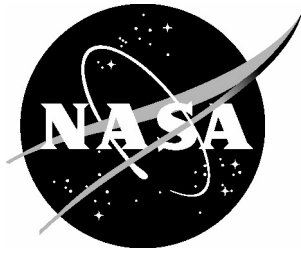


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Portable Integrated Wireless Device Threat Assessment to Aircraft Radio Systems

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December 2004

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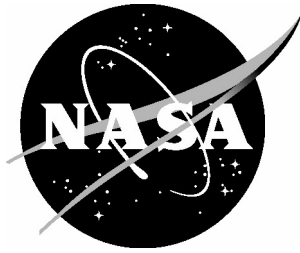
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Acronyms

AP	Access Point
ATCRBS	Air Traffic Control Radar Beacon System
CB	Citizen Band
DME	Distance Measuring Equipment
DSSS	Direct Sequence Spread Spectrum
DUT	Device-Under-Test
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FHSS	Frequency Hopping Spread Spectrum
GPS	Global Positioning System
GS	Glideslope
HIRF	High Intensity Radiated Fields
IEEE	Institute of Electrical and Electronic Engineering
ILS	Instrument Landing System
ISM	Industrial, Scientific, Medical
LaRC	Langley Research Center
LOC	Localizer
MAX	Maximum
MLS	Microwave Landing System
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
OFDM	Orthogonal Frequency Division Multiplexing
PC	Personal Computer
PDA	Personal Digital Assistant
PED	Portable Electronic Device
RC	Reverberation Chamber
RSW	Resolution Bandwidth
RTCA	RTCA, Inc.
SA	Spectrum Analyzer
SAC	Semi-Anechoic Chamber
TCAS	Traffic Collision Avoidance System

TRP	Total Radiated Power
VEE	Visual Engineering Environment
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
WLAN	Wireless Local Area Network

List of Symbols

P_{TotRad}	Total radiated power within measurement resolution bandwidth
π	Universal constant = 3.141592654
η_{Tx}	Transmit antenna efficiency factor
CF	Chamber Calibration Factor (dB)
CLF	Chamber Loading Factor
D_G	Directivity
E	Electric Field Intensity (V/m)
$EIRP$	Effective Isotropic Radiated Power (W)
IL	Empty chamber Insertion Loss
$P_{SAMeas(dBm)}$	Maximum receive power measured at the spectrum analyzer (dBm) over one stirrer revolution
$P_{Xmit(dBm)}$	Power transmitted from source (dBm)
R	Distance (m)
TRP	Total Radiated Power (within measurement resolution bandwidth)

Abstract

An assessment was conducted on multiple wireless local area network (WLAN) devices using the three wireless standards for spurious radiated emissions to determine their threat to aircraft radio navigation systems. The measurement process, data and analysis are provided for devices tested using IEEE 802.11a, IEEE 802.11b, and Bluetooth as well as data from portable laptops/tablet PCs and PDAs (grouping known as PEDs). A comparison was made between wireless LAN devices and portable electronic devices. Spurious radiated emissions were investigated in the radio frequency bands for the following aircraft systems: Instrument Landing System Localizer and Glideslope, Very High Frequency (VHF) Communication, VHF Omnidirectional Range, Traffic Collision Avoidance System, Air Traffic Control Radar Beacon System, Microwave Landing System and Global Positioning System. Since several of the contiguous navigation systems were grouped under one encompassing measurement frequency band, there were five measurement frequency bands where spurious radiated emissions data were collected for the PEDs and WLAN devices. The report also provides a comparison between emissions data and regulatory emission limits.

1 Introduction

Portable electronic devices (PEDs) have brought about flexibility for a more mobile, productive, and entertained society. A majority of air travelers carry onboard a PED for work or entertainment to pass hours of travel time to their final destination. Airlines abide by FAA regulation to permit the operation of non-intentional transmitting devices such as laptop computers, personal digital assistants (PDAs), CD/MP3 players, DVD players and electronic video games during non-critical phases of flight. Flight attendants instruct passengers to turn off and stow all electronic devices just after the main cabin door is closed, and they are to remain off until an announcement is made giving permission that they may be operated again. At this point, the flight is at cruising altitude, above the designated 10,000 feet altitude restriction [1].

Wireless local area networks (WLANs), citizen band (CB) radios, cellular phones, and two-way communication devices are classified as prohibited intentional transmitters by the airlines and cannot be operated onboard at all critical phase of flight, which includes taxiing down the runway, ascending, descending and landing. These types of electronics do not require certification to aircraft standards. The spurious emissions that radiate from such PEDs in the aircraft's communication and navigation systems frequency band are therefore unknown or have yet to be measured to determine if they meet the RTCA/DO-160D spurious emission limit requirements for flight.

PEDs and WLAN devices have proliferated since they are more affordable for consumers to purchase and public Internet service is readily available at various businesses around larger cities, especially within airport terminals. Newer laptops and PDAs have integrated WLAN devices, which makes it more difficult for flight crews to determine if the electronic devices are permitted or prohibited. Airlines would like to provide their passengers with additional information technology services. Therefore, airlines have a growing concern with passengers bringing their covert integrated intentionally transmitting PEDs onboard an aircraft. However, airlines have to ensure that aircraft safety takes precedence, because RF

interference to aircraft systems can cause interruptions in communication and navigation systems (com/nav) putting the plane in jeopardy.

1.1 Objective

This report expands on a previous threat assessment of WLAN devices [2] performed by the National Aeronautics and Space Administration Langley Research Center (LaRC). In the previous effort, the goal was to document a test procedure, which could be used to test other wireless devices using IEEE 802.11a, 802.11b and Bluetooth standards. Also included in the prior effort was an assessment of the collected data that revealed WLAN devices were not any worse than PEDs, especially when compared to aircraft certification limits. In this effort, the focus is on spurious radiated emissions from integrated WLAN devices in current electronic technologies, which are assessed to determine their threat to passenger carrier aircraft com/nav systems by employing prior test procedures to acquire the data.

Some of the measurement frequency bands encompass several aircraft com/nav system frequency bands, since many of the com/nav frequencies are contiguous or overlap. Table 1.1-1 lists aircraft systems located within each measurement frequency band such as Localizer (LOC), Glideslope (GS), Very High Frequency Communication (VHF), VHF Omnidirectional Range (VOR), Traffic Collision Avoidance System (TCAS), Air Traffic Control Radar Beacon System (ATCRBS), Distance Measuring Equipment (DME), Global Positioning System (GPS) and Microwave Landing System (MLS). Band 1b is an extension of the prior effort's Band 1 [2] to include the Very High Frequency (VHF) communication system. In [2], Band 1 frequency range was 105 MHz – 120 MHz and Band 1a frequency range was 116 MHz – 140 MHz as defined in a follow-up study to [2] to include the VHF band. The FAA requested that previous PEDs and WLAN devices spurious emissions tests be conducted in the VHF band as well, so a separate effort was completed testing them in Band 1a which will be amended to [2]. Therefore, the following equation simply states how Band 1b is formed.

$$\text{Band 1b} = \text{Band 1} + \text{Band 1a} \quad (\text{Eq. 1.1-1})$$

Table 1.1-1: Correlates Emission Measurement Bands and Aircraft Radio Systems

Measurement Band Designation	Measurement Freq. Range (MHz)	Aircraft Systems Covered	Spectrum (MHz)
Band 1b	105 – 140	LOC	108.1 – 111.95
		VOR	108 – 117.95
		VHF	118 - 137
Band 2	325 – 340	GS	328.6 – 335.4
Band 3	960 – 1250	TCAS	1090
		ATCRBS	1030
		DME	962 - 1213
		GPS L2	1227.60
		GPS L5	1176.45
Band 4	1565 – 1585	GPS L1	1575.42 ± 2
Band 5	5020 - 5100	MLS	5031 – 5090.7

2 WLAN Emissions

2.1 WLAN Overview

WLAN generally encompasses IEEE 802.11 standards and wireless personal area network (WPAN) includes the IEEE 802.15 standard, which is Bluetooth 1.1. WLAN is an extension of the wired infrastructure enabling the end user freedom to roam, yet still have access to the intranet through the use of radio frequency (RF). WPAN alleviates the need for proprietary cables between smaller pieces of a larger system by using RF to send and receive information. In order to simplify, this paper Bluetooth will also be categorized as WLAN.

2.1.1 IEEE 802.11a

IEEE 802.11a is capable of high-speed and high-bandwidth applications in a sparsely populated frequency band. This wireless standard operates in the Unlicensed National Information Infrastructure (U-NII) band designated from 5.15-5.825 GHz. The Federal Communication Commission (FCC) divided the total 300 MHz into three 100 MHz bands to accommodate three different maximum power outputs. Table 2.1-1 lists the three bands, the corresponding power levels, additional data rates and number of channels. 802.11a supports data rate speeds up to 54 Mbps by utilizing Orthogonal Frequency-Division Multiplexing (OFDM), yet it has the capability to decrease the rate when the distance between the access point (AP) and mobile user increases.

2.1.2 IEEE 802.11b

IEEE 802.11b resides in the populated unlicensed 2.4 GHz Industrial, Scientific, and Medical (ISM) frequency band. Direct Sequence Spread Spectrum (DSSS) modulation technique along with Complementary Code Keying enables 802.11b to transfer data at 11 Mbps. The rate is dependent on the distance between the AP and the mobile user and the rate will automatically adjust when necessary. Maximum transmit power for 802.11b is 100 mW. The standard allows 1000 mW if power control is built into the AP and PC cards. Since 802.11b stemmed from the DSSS 802.11 wireless standard, the two protocols can communicate with each other, yet they can only exchange data at 1 or 2 Mbps because that is the highest rate DSSS 802.11 is able to transmit. Table 2.1-1 includes information about distance, number of channels and additional data rates.

2.1.3 Bluetooth

Bluetooth is a short-range radio technology with the capability to maintain a link through walls while operating in the populated ISM frequency band. Bluetooth employs the Frequency Hopping Spread Spectrum (FHSS) technique to avoid interference from other devices establishing a robust communication link. Frequency hopping occurs 1600 times per second among the seventy-nine 1 MHz channels. The ideal data rate that is supported by this wireless standard is 2 Mbps, however, the data rate is significantly reduced to 721 Kbps due to protocol overhead. Protocols for Bluetooth handles both data and limited voice communication. Bluetooth has three power classes, which are associated with the distance between two enabled devices. Table 2.1-1 includes information about range and power classes. Class 1 devices are required to have a power control feature to limit the transmit power over 1 mW (0 dBm).

Table 2.1-1: Wireless Technology Parameters

Wireless Technology	Frequency Band (GHz)	Typical Data Rates (Mbps)	Number of Channels	Maximum Output Power (mW)	Typical Range (meter)
802.11a		6, 12, 24, 54			
Low Band	5.15 – 5.25		4	40	50
Middle Band	5.25 – 5.35		4	250	50
High Band	5.725 – 5.825		4	1000	50
802.11b	2.4 – 2.4835	1, 2, 5.5, 11	11	100 or 1000	24 - 100
Bluetooth	2.4 – 2.4835	2 (optimal)	79		
Class 1				100 (20 dBm)	Up to 100
Class 2				2.5 (4 dBm)	Up to 10
Class 3				1 (0 dBm)	0.1 to 10

2.2 Measurement Procedure Description

Mode-stirring in a reverberation chamber was selected because it produces repeatable measurements and reduces test time as compared to other methods. A methodology using mode-stirring for procuring emissions data is presented in this section. Explanations of instrumentation, chamber setup, and spectrum analyzer parameters for obtaining practical measurements are discussed.

2.2.1 Test Facility

Emission measurements were conducted in two of the three reverberation chambers (RCs) located at the NASA LaRC High Intensity Radiated Fields (HIRF) Laboratory. The National Institute of Standards and Technology (NIST) conducted field uniformity characterization of these three chambers. The results indicated superior field uniformity performance compared with other existing chambers. Further details regarding their performance are described in [3]. Although the largest chamber (14.33m x 7.01m x 2.90m) utilized has the capability to test all the emission measurement bands, intermittent low-level noise interference was observed in the higher bands, so a smaller chamber (2.72m x 2.13m x 2.90m) was also used. The large RC's lowest useable frequency is approximately 100 MHz with ± 2 dB variation and accommodates test measurement frequency Bands 1b and 2 (Table 1.1-1). The smaller RC's lowest useable frequency is approximately 300 MHz with ± 2 dB variation and accommodates test measurement frequency Bands 3, 4 and 5.

RC's produce radiated emission measurements in terms of total radiated power (TRP) rather than electric field strengths as generated in a semi-anechoic chamber (SAC). The RC method when compared to a SAC method, is advantageous because the orientation of the device-under-test (DUT) is not considered; thus, the number of tests is considerably reduced. Repeatability is another advantage to conducting tests in a RC, and the method does not suffer from measurement uncertainty caused by multipath affects.

2.2.2 Measurement Methodology

RCs exercise several methods to produce a statistically uniform, isotropic, randomly polarized field. Chambers operated at LaRC are capable of mode-tuned and mode-stirred techniques to perturb the radiated electromagnetic fields in order to achieve a statistical distribution. Further details of these two methods are found in [4]. The mode-stirring method was chosen over mode-tuned because of a simplistic setup and reduced test time. When the metallic stirrer rotates continuously in time, this is referred to as

mode-stirring. Rotation by fixed steps for one rotation is referred to as mode-tuning. In mode-tuning, at each new stirrer position, a small time interval is allotted for DUT response time as in susceptibility or test receiver's response time for emission measurements. Test receivers used in this study have suitable response times to accommodate mode-stirring. This is preferable for emission measurements because numerous samples at each frequency are achieved per stirrer rotation.

Emission measurements taken from the receive antenna are corrected for chamber loss to obtain the power radiated by a test article inside the chamber. Maximum received power measurements are completed after one stirrer rotation. Radiated power from the DUT is determined by using the maximum receive power equation obtained from [5].

$$P_{TotRad} = \frac{P_{MaxRec} * \eta_{Tx}}{CLF * IL} \quad (\text{Eq. 2.2-1})$$

where

P_{TotRad}	radiated power from the DUT within the measurement bandwidth
P_{MaxRec}	maximum receive power over one continuous stirrer rotation within the measurement bandwidth
η_{Tx}	transmit antenna efficiency factor used in chamber calibration; unity is assumed for antennas used
CLF	chamber loading factor (includes the DUT and the test operator)
IL	empty chamber insertion loss determined during chamber calibration that equals P_{MaxRec} / P_{Input} where the input power is supplied by a transmit antenna into the chamber

The equation specified above is an overview for performing emission measurements in a RC according to IEC standards. Measurements conducted during this research effort can be simplified to the following practical equations 2.2-2 and 2.2-3. In Eq. 2.2-2, measuring the chamber loss (L_{Chmbr}) incorporates both chamber loading factor and insertion loss, eliminating the need to measure CLF and IL separately. CLF correction is applied only in cases where the DUT and personnel do not cause the measured field uniformity in the chamber during calibration to exceed the ± 3 dB uncertainty tolerance [5]. Hence, the DUT and DUT operator can be present in the chamber during calibration, especially when the measurement is taken at one-location rather than averaging measurements taken at multiple locations.

$$\begin{aligned} CF &= (P_{Xmit} (dBm) - P_{SAMeas} (dBm)) \\ &= L_{Chmbr} (dB) + L_{RecCable} (dB) + L_{XmitCable} (dB) \end{aligned} \quad (\text{Eq. 2.2-2})$$

where

CF	Calibration Factor of the chamber (dB)
----	----------------------------------------

$L_{Chmbr} (dB)$ chamber loss (dB), also expressed as $-10\log_{10}(CLF*IL)$

$L_{RecCable} (dB)$ receive cable loss (dB)

$L_{XmitCable} (dB)$ transmit cable loss (dB)

$P_{Xmit} (dBm)$ power transmitted from source (dBm)

$P_{SAMeas} (dBm)$ maximum receive power measured at the spectrum analyzer (dBm) over one stirrer rotation

In order to isolate the SA measured radiated power from the DUT, losses from the transmit cable and calibration factor are mathematically removed from the P_{SAMeas} in Eq. 2.2-3.

$$P_{TotRad} (dBm) = P_{SAMeas} (dBm) - L_{XmitCable} (dB) + CF \quad (\text{Eq. 2.2-3})$$

Several pieces of equipment were utilized to obtain emissions data from the laptop/PDA and WLAN device. The data collection and calibration instrumentation included a PC test controller system, tracking source, spectrum analyzer (SA), filters and pre-amplifiers, IEEE 488 Bus, antennas (log periodic, Global Positioning System (GPS), and double ridge horn) and stirrer controller. The equipment necessary to communicate with the wireless DUT included a wired laptop computer, router, access point (AP, either 11a or 11b), bandpass filters, attenuator and Ethernet cables. The instruments were connected as shown in Figure 2.2-1. In order to test Bluetooth devices, a laptop computer was loaded with a software interface program to control the Bluetooth test set through a parallel connection, and an antenna from the test set was brought into the chamber through a bulkhead panel in the wall. This was done to isolate the noise from various devices.

Measurements initially began by determining transmit cable and chamber calibration losses. Transmit cable calibration determines the transmit path loss by injecting a known power from the tracking source through the cable to the antenna connection, which is attached to a spectrum analyzer that measures the loss. This step is repeated for each measurement frequency band. A chamber calibration was performed next. Once again, a known power level from the source was injected through the transmit antenna into the chamber where the stirrers are continuously rotated at a constant rate. Power entered the receive antenna and propagated through the receive path into the spectrum analyzer, where the maximum power was recorded. The SA is able to capture maximum power levels across a measurement frequency band due to connections between the SA and tracking source synchronizing frequency sweeps. Both calibration data are included in Eq. 2.2-2 and is further applied in Eq. 2.2-3.

Emission measurements were taken once the source was removed and the transmit path was terminated by a 50 Ω connector to prevent leakage from the source or additional RF entering the chamber. Radiated emission measurements began with each DUT powered off in order to measure the noise floor levels in each band. Then the DUT was powered on and radiated emission measurements were performed as each device cycled through several test modes in five frequency bands. The SA was set in maximum hold mode while continuously sweeping the measurement frequency band until the dwell time concluded. Dwell time ensures that an adequate number of sweeps have been recorded by the SA to update the

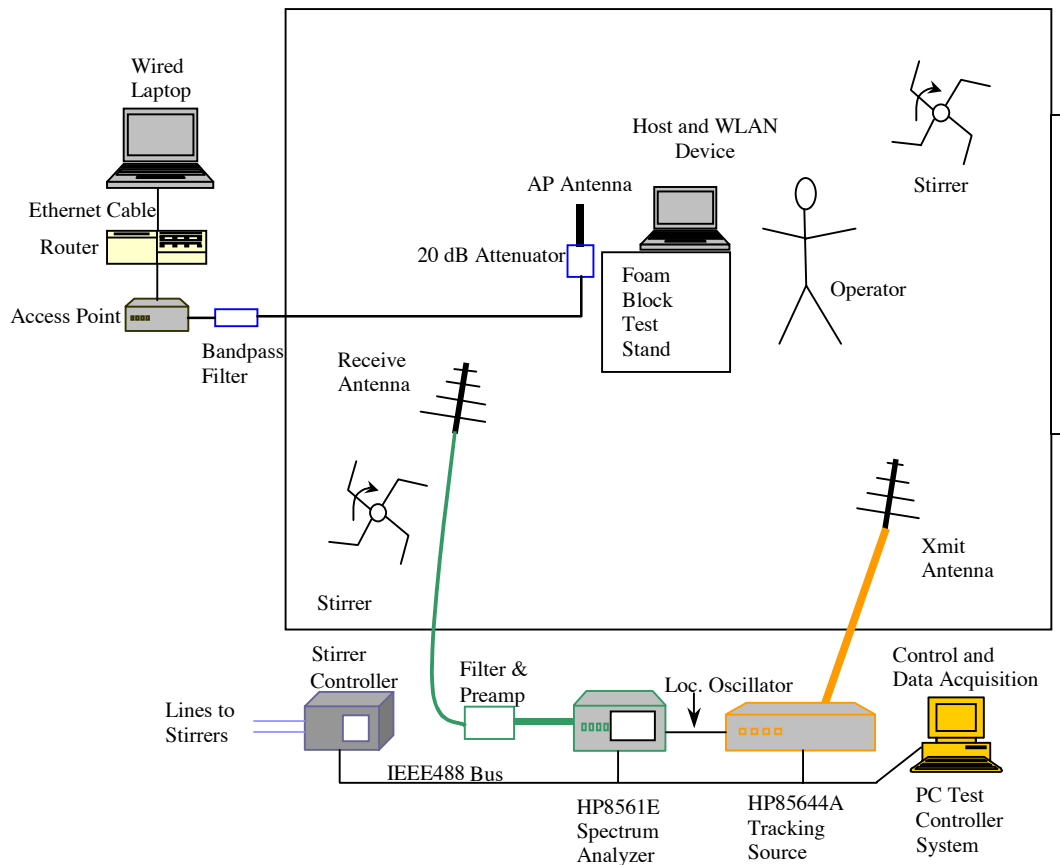


Figure 2.2-1: Instrumentation setup for DUT emission measurements.

Spectrum Analyzer Parameters

Spurious radiated emission test parameters used in this report were based on those that were established in the prior test procedure [2]. Table 2.2-2 provides the resolution bandwidths and sweep times used the HP8561E SA for each measurement frequency band. Several standards were consulted, as seen in Table 2.2-3, to determine the best resolution bandwidth to use to obtain accurate measurements in the least amount of time. The resolution bandwidth chosen for each frequency band concurs with those stated in the RTCA DO-160D since it was produced to address spurious radiated emission levels potentially interfering with commercial aircraft com/nav systems. The standard states that bandwidths of 10 kHz "...shall be used in the notches with no correction factor being applied". Having selected a reasonable resolution bandwidth as a compromise for best sensitivity minimizes sweep times, especially in the case of Band 5 and Band 3 [2]. Band 5 would have a long sweep time if a 10 kHz resolution bandwidth were used; therefore, 30 kHz was chosen to provide a faster sweep time without losing the capability of discernable peaks in the trace.

Table 2.2-2: Resolution Bandwidths and Sweep Times for Measuring Spurious Radiated Emissions in Aircraft Radio Frequency Bands

Frequency Band Designation & (Chamber)	Aircraft Systems	MHz	Resolution Bandwidth kHz	Spectrum Analyzer Sweep Time (ms) (HP8561E)
1b (A)	VOR , ILS LOC, VHF	105 – 140	10	880
2 (A)	ILS GS	325 – 340	10	375
3 (C)	DME, TCAS, ATCRBS, GPS L2	960 – 1250	100	73
4 (C)	GPS L1	1565 – 1585	10	500
5 (C)	MLS	5020 - 5100	30	230

Table 2.2-3: Several Standards' Measurement Bandwidth Recommendation

Frequency Band	RTCA DO-160D [9]	RTCA DO-233 [3]	ANSI C63.4-2000 [10]	ETSI EN 301 908-7 V1.1.1 [11]	MIL-STD-462D [8]
30-400 MHz	10 kHz	100 kHz	100 kHz	100 kHz	100 kHz
400- 1000 MHz	100 kHz*	100 kHz	100 kHz	100 kHz	100 kHz
Over 1000 MHz	1 MHz*	1 MHz	1 MHz	1 MHz	1 MHz

2.2.3 Host Device Baseline

WLAN devices transform laptops, tablet PCs and PDAs into devices that communicate with each other and fixed networks through designated radio frequencies (RFs). WLAN transmitters do not function independently and must be installed in a host device. A host device is a portable electronic device (PED) that can be mobile while maintaining a link to exchange information with other PEDs. Table 2.2-4 presents the laptops, tablet PCs and PDAs used as hosts in this effort. All hosts were used since each contained an integrated wireless LAN card.

For these tests, spurious radiated emission measurements taken from host devices operated in idle, screensaver, file transfer, CD, and DVD modes in each frequency band formed a maximum radiated peak envelope for each PED when the separate modes were plotted together. Section 2.3 contains further explanation and discussion of the graphs. The flowerbox screensaver was selected to be a large, smooth, checkerboard cube pattern that spins and blooms at maximum complexity. The file transfer mode transfers a file from the hard drive to the Personal Computer Memory Card International Association (PCMCIA) slot mounted microdrive. Idle mode testing was conducted as a normal desktop screen is displayed. In order to exercise the video and audio cards, a CD and DVD were played. Appendix B contains results of the plotted data.

PED emissions were independently measured to create a baseline by combining idle and file transfer modes. A comparison between a DUT (WLAN and host unit) and the host baseline revealed the effects the WLAN device adds to the host emissions. The host baseline was directly compared to the DUT's idle, ping storm and file transfer magnitudes across a measurement frequency band. Ping storm mode consisted of sending a continuous stream of querying packets to the DUT and receiving confirmation

from the device. A file transfer consisted of both computer simultaneously sending and receiving files through the RF communication link.

Table 2.2-4: Models of Host Devices

Host Designation	Manufacturer	Model
LAP9	Dell	Latitude D600
TAB1	Acer	Travelmate C100
TAB2	Compaq	TC1000
TAB3	Viewsonic	Tablet PC V1100
PDA1	Palm	M515
PDA3	Palm	Tungsten T
PDA4	Palm	Tungsten W

2.2.4 Wireless Device Testing

Emission measurements data was collected on 802.11a, 802.11b, and Bluetooth integrated wireless cards in PEDs among five measurement bands. Information about the one 802.11a, four 802.11b and four Bluetooth devices are given in this section. Further details on obtaining the emissions data from wireless DUTs are included along with photographs of test instrumentation setup.

WLAN Devices Tested

Since the WLAN devices were integrated into their electronic hosts, little information could be found about the particular devices except what is shown in Table 2.2-5 – Table 2.2-7. All devices were compatible with their associated AP (Proxim Harmony 802.11a and Cisco 802.11b) or Bluetooth test set as well as other devices within their standard. Tests conducted on 11A-7 revealed that the card is incapable of operating in turbo mode. Turbo mode is any data speed beyond 54 Mbps at three additional center frequencies (5.210 GHz, 5.250 GHz, 5.290 GHz) that are considered proprietary by wireless card manufacturers. The software interfaces to 802.11a or 802.11b devices did not include any feedback information about the maximum output power, data rate, or operating channels. It was assumed that the cards were set to automatic data rate and channel selection, which synchronizes with the corresponding configured AP.

Bluetooth devices did not have any option controls or feedback capabilities within the software, except showing the Bluetooth addresses of other devices in the area. Connection between a device and test set was simple to establish, which is discussed in a later section.

Table 2.2-5: 802.11a Devices Tested

DUT Designation	Manufacturer	Model	Host Designation
11A-7	Dell	TrueMobile 1400	LAP9

Table 2.2-6: 802.11b Devices Tested

DUT Designation	Manufacturer	Model	Host Designation
11B-14	Dell	TrueMobile 1400	LAP9
11B-15	Orinoco	Mini PC Card	TAB1
11B-16	Compaq	802.11b WLAN Mini PC Card	TAB2
11B-17	Intel	Pro/Wireless 11Mbps	TAB3

Table 2.2-7: Bluetooth Devices Tested

DUT Designation	Manufacturer	Model	Host Designation
BLUE-13	N/A	N/A	PDA3
BLUE-15	Dell	TrueMobile 300	LAP9
BLUE-16	Belkin	F8T001	LAP4
BLUE-SYS	Palm & Emtac	SD card & GPS receiver	PDA1

WLAN Device Radiated Emission Measurements

Chamber characteristics and noise levels in specific frequency bands required the use of two chambers. Instrumentation used for calibration and collection of emission measurements included a HP8561E spectrum analyzer, a HP85644A tracking source, RF filters, pre-amplifiers, transmit and receive antennas, and a control laptop computer. Log periodic, double ridge horn, and GPS survey antennas were used in the appropriate band to transmit and receive energy. Preamplifiers were included in the receive path to reduce the effective noise floor. The RF filters in the receive path blocked signals related to wireless device in-band transmission frequencies while allowing monitoring of out-of-band signals.

Calibration and emission measurements utilize the previously mentioned measurement procedures. Instrumentation is approximately positioned as seen in Figure 2.2-1. Calibrations are the first measurements to be obtained and used to normalize emission measurements. If the connection of the wireless LAN communication equipment into the chamber from Figure 2.2-1 is removed, the items that remain are the calibration setup. The DUT and the operator are present inside the chamber during the calibration because they are energy absorbers that are part of the chamber loss. However, the DUT remains powered off and the operator is grounded to prevent electrostatic discharge from effecting measurements. The control software records calibration measurements, which are then applied to DUT power measurements for normalization in each frequency band.

A quiet RF environment had to be established before proceeding with radiated emission measurements. Noise floor measurements were conducted to determine the ambient environment including a powered off DUT, an operator, and AP test set or Bluetooth test set power on. The filters inline with the AP or Bluetooth single chamber fed antenna permit transmitted RF while blocking other RFs that may have coupled onto the cable. This ensures the data collected across the frequency band is a result of the DUT.

The environment-monitoring program downloads measurements once the set dwell time has concluded. Minimum established dwell time for conducted tests (chamber calibration or emission measurements) was usually 120 seconds. Except in the case of the cable calibration, a dwell time of 2 seconds was applied because a RC was not required. In cases pertaining to 802.11a/b DUT measurements, the dwell time increased to 180 seconds since the test article channel was changed three times during a measurement. Thus, each channel had approximately 60 seconds of dwell time.

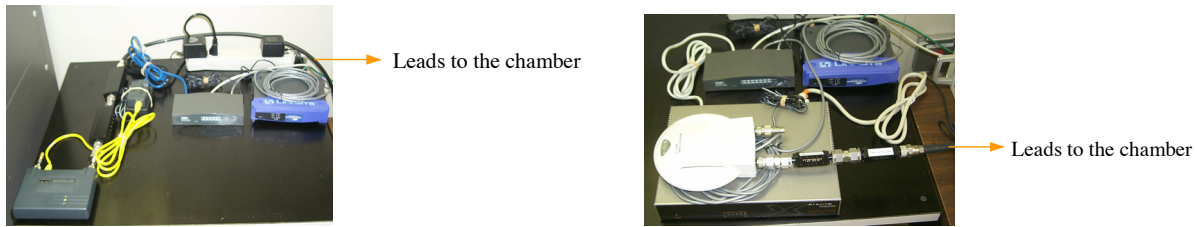


Figure 2.2-2: 802.11b AP test controller on the left and 802.11a AP test controller on the right.

Figure 2.2-2 provides a picture of the 802.11a/b wireless APs test set setup that was located outside the chamber. Included in the pictures are a router, AP, and an 802.11a AP controller, each connected to a hub by RJ-45 network cables. Also shown in the photograph is a 50 Ω connector capping one of the antenna ports on the AP. On the other port are two filters cascaded together to block any additional frequencies other than the transmission frequency from entering the chamber. Excluded from this picture is a laptop computer also connected to the hub by an Ethernet network cable, which interfaces with the AP and is used to change the options, as well as, communicate with the laptop computer inside the RC.

The laptop computer and AP combination comprised the test set used to switch data rates and channels during idle, ping storm and duplex file transfer emission measurements for 802.11a/b DUTs. Tests were composed of a data rate, mode, and one of three channels. Approximately one minute of test time was allotted for each channel.

An Agilent E1852 Bluetooth test set was utilized to control the modes of the Bluetooth devices for emission measurement collection. Bluetooth emissions were conducted in idle and normal paging modes. Designated channels do not exist because Bluetooth uses a frequency-hopping technique to transfer data; therefore a two-minute dwell time was sufficient for the SA to receive maximum peak power levels, which were recorded by the laptop.

Figure 2.2-3 illustrates the control and data acquisition instrumentation located outside the RC. An HP8561E SA and an HP85664A tracking source are pictured. Frequency synchronization between the tracking source and the SA is possible through the local oscillator connection, and three additional rear connections were made according to manufacturers specifications. For measurements in the GPS band, a power source is connected to a bias tee to power the amplifier within the GPS survey antenna, shown in Figure 2.2-4.

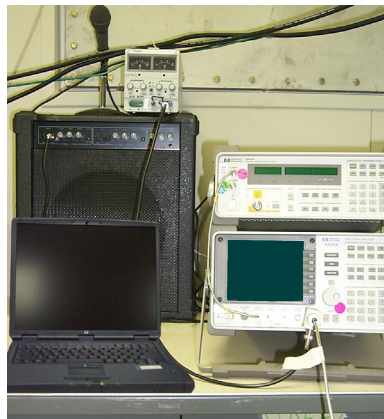


Figure 2.2-3: Control and data acquisition setup outside the RC for Band 4 (1565 MHz – 1585 MHz).



Figure 2.2-4: RC and 802.11b WLAN setup for Band 4 (1565 MHz – 1585 MHz).

Test Matrix

Table 2.2-8 and Table 2.2-9 are portions of 802.11 test matrices for emission tests. An assigned DUT operates in three different test modes and pre-selected channels during five measurement frequency bands. The DUTs function differently in idle, ping storm, and duplex file transfer (Xfer) modes; therefore affecting radiated emission magnitudes of the host device's unique emissions pattern. Various modulation schemes are selected to achieve the different data rates. High, medium, and low channels are selectable within the 802.11a/b transmission frequency bands to change a parameter that may alter emission levels. Changing data rates, channels and modes of each DUT should produce the highest emission levels in each measurement frequency band.

Table 2.2-8: 802.11a Test Matrix

Device Under Test	Test Modes and Channels	Bands
11A-7	Idle	1b-5
11A-7	Ping Storm AP Data Rate 6 Channels 36 48 64	1b-5
11A-7	Ping Storm AP Data Rate 12 Channels 36 48 64	1b-5
11A-7	Ping Storm AP Data Rate 24 Channels 36 48 64	1b-5
11A-7	Ping Storm AP Data Rate 36 Turbo Channel 42 50 58	1b-5
11A-7	Duplex File Xfer AP Data Rate 6 Channel 36 48 64	1b-5
11A-7	Duplex File Xfer AP Data Rate 12 Channel 36 48 64	1b-5
11A-7	Duplex File Xfer AP Data Rate 24 Channel 36 48 64	1b-5
11A-7	Duplex File Xfer AP Data Rate 36 Turbo Channel 42 50 58	1b-5

Table 2.2-9: 802.11b Test Matrix

Device Under Test	Test Modes and Channels	Bands
11B-14	Idle	1b-5
11B-14	Ping Storm AP Data Rate 1 Channels 1 6 11	1b-5
11B-14	Ping Storm AP Data Rate 2 Channels 1 6 11	1b-5
11B-14	Ping Storm AP Data Rate 11 Channels 1 6 11	1b-5
11B-14	Duplex File Xfer AP Data Rate 1 Channels 1 6 11	1b-5
11B-14	Duplex File Xfer AP Data Rate 2 Channels 1 6 11	1b-5
11B-14	Duplex File Xfer AP Data Rate 11 Channels 1 6 11	1b-5

Table 2.2-10 is a portion of the Bluetooth test matrix providing the DUTs operational test modes for each measurement frequency band. The two test modes are idle and normal paging for integrated Bluetooth devices. A majority of the Bluetooth devices are controlled by the test set except for one designated as BLUE-SYS. This particular Bluetooth system contains two Bluetooth devices communicating with one another and they are the EMTAC GPS receiver and PDA-1 with a Toshiba Bluetooth card inserted. In idle mode for BLUE-SYS, both devices were on with each searching for the other Bluetooth device. In communication (Comm) Mode for this system, a communication link was established between the two devices and emission data was taken.

Table 2.2-10: Bluetooth Test Matrix

Device Under Test	Test Modes	Bands
BLUE-13	Idle	1b-5
BLUE-13	Normal Paging	1b-5

2.2.5 Data Reduction

Data reduction and plotting software created in the Visual Engineering Environment (VEE) [6] simplified the reduction of numerous emission measurement data files. Reduction of data files produced graphical comparisons between non-intentional transmitters (PEDs) and converted PEDs to intentional transmitters through WLAN cards for analysis. Composite envelopes were produced for both PEDs and each WLAN standard to determine the threat to com/nav systems. The reduction portion of the software determined the maximum magnitudes at each individual frequency from several test mode data files and created an envelope. This step was repeated numerous times until a PEDs composite envelope and WLAN standard composite envelope was generated in each measurement band.

A reduction process overview is illustrated in Figure 5. In order to achieve data envelopes, grouped data files are compared with each other to achieve maximum (MAX) magnitude at each frequency within the measurement band. The term “test” article refers to host devices or DUTs (host plus WLAN devices). Once this process has generated each test article envelope and composite envelope, then a comparison is made from the plot.

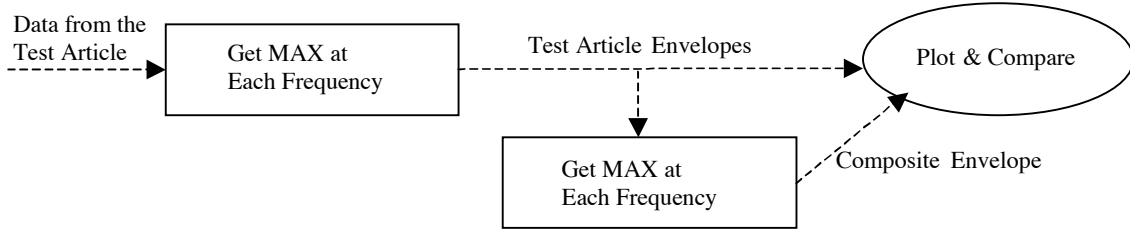


Figure 2.2-5: Data reduction process.

Graphs provided in Appendices A and B show the data reduction process that concludes with graphs presented in section 2.5. Appendix A contains graphs showing the DUT test modes that went through the reduction process to produce the results seen in section 2.3. Appendix B contains graphs showing host test modes that went through the reduction process to produce the results seen in section 2.4. Composite envelopes from section 2.3 and 2.4 are plotted simultaneously for analysis, as depicted in Figure 2.2-6.

The following algorithms give a synopsis of the generation of test article envelopes.

For each test article in each measurement band,

$$\text{MAX}[\text{Test Article}_{\text{Emissions}}]_{\text{All_Modes}} \Rightarrow \text{Test Article}_{\text{Envelope}}$$

For each measurement band,

$$\text{MAX}[\text{Test Article}_{\text{Envelope}}]_{\text{All_Test Article}} \Rightarrow \text{Test Article}_{\text{Composite_Env}}$$

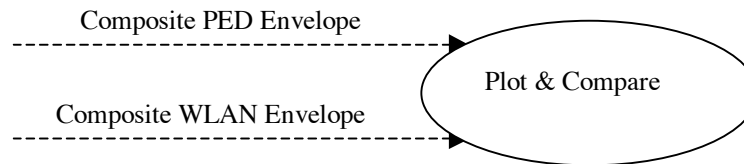


Figure 2.2-6: Graphs containing both composite envelope traces for comparison, see Section 2.5.

2.3 Test Results for WLAN Devices

These intermediate graphs provide a visual interpretation following the data reduction process. Graphs presented in this section further reduce WLAN data found in Appendix A and are grouped according to measurement bands. Idle, ping storm envelope, and file transfer envelope files are compared against each other to obtain the maximum radiated power level for each frequency, which produces each WLAN device envelope. Next, each WLAN envelope file is compared against all other to obtain the maximum radiated power level at each given frequency producing the composite envelope. The graph has each WLAN device envelope and composite envelope plotted for each WLAN standard. Some or all portions of a WLAN device envelope trace are not visible because the composite envelope overlays it.

2.3.1 Band 1b (105 MHz to 140 MHz)

Data presented in Figures 2.3-1 to 2.3-3 were acquired in a measurement frequency band comprised of the VOR, ILS LOC, and VHF aircraft systems. Individual WLAN device envelopes and a composite envelope trace including all devices in each standard are seen in the following plots.

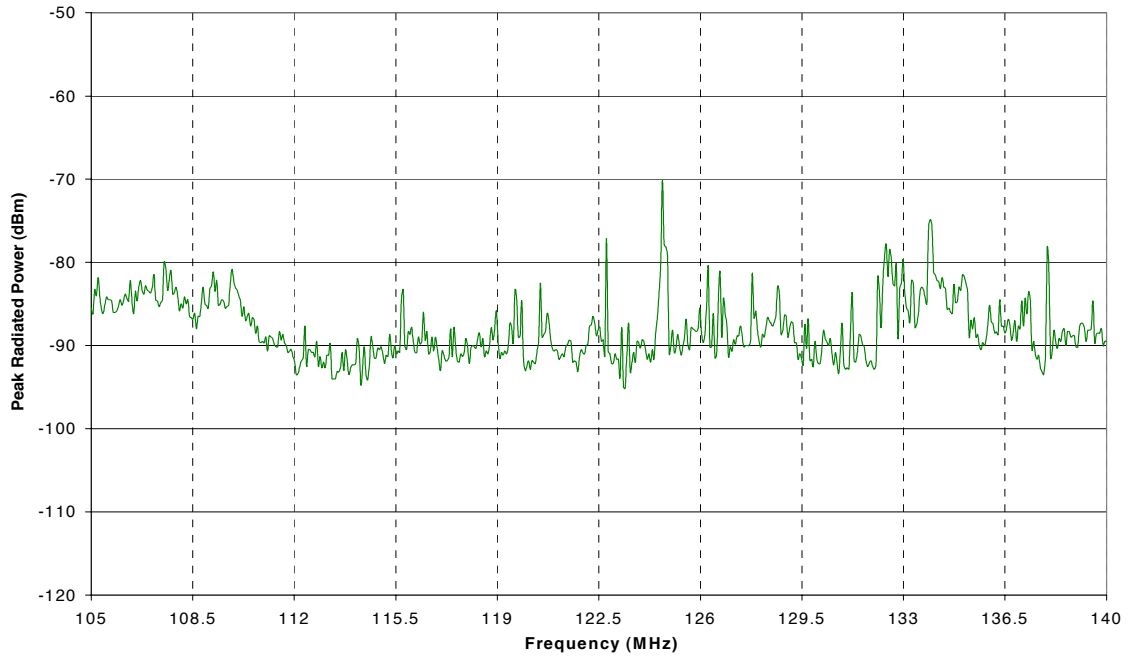


Figure 2.3-1: WLAN 802.11A-7 Device Envelope for Band 1b.

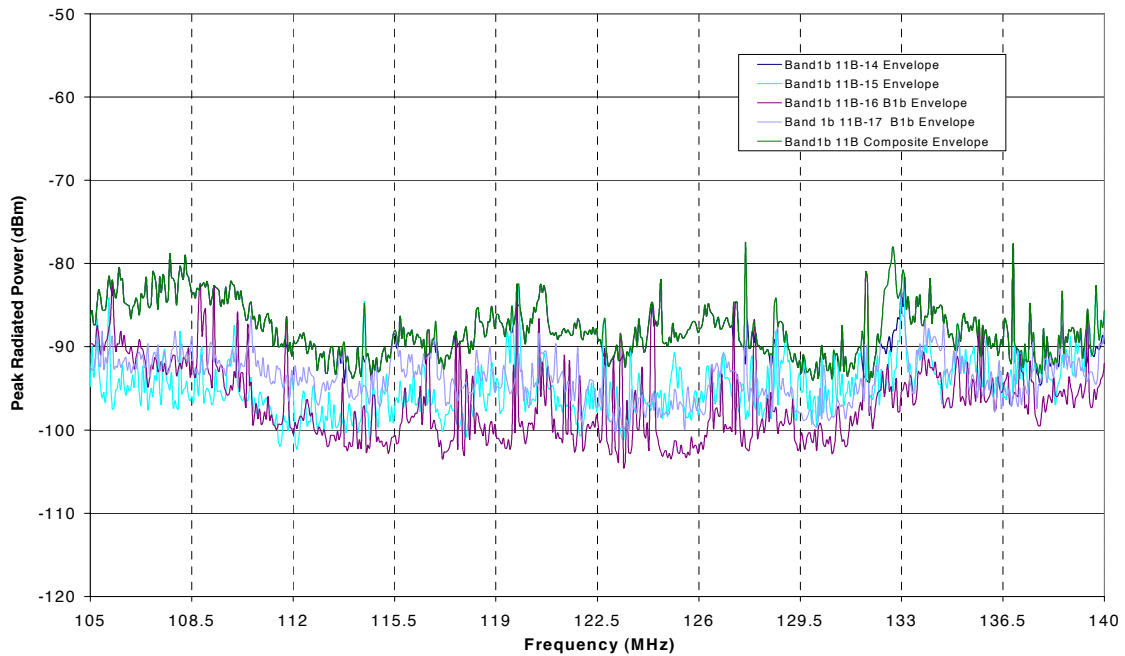


Figure 2.3-2: Individual 802.11b WLAN Device Envelopes and Their Composite Envelope for Band 1b.

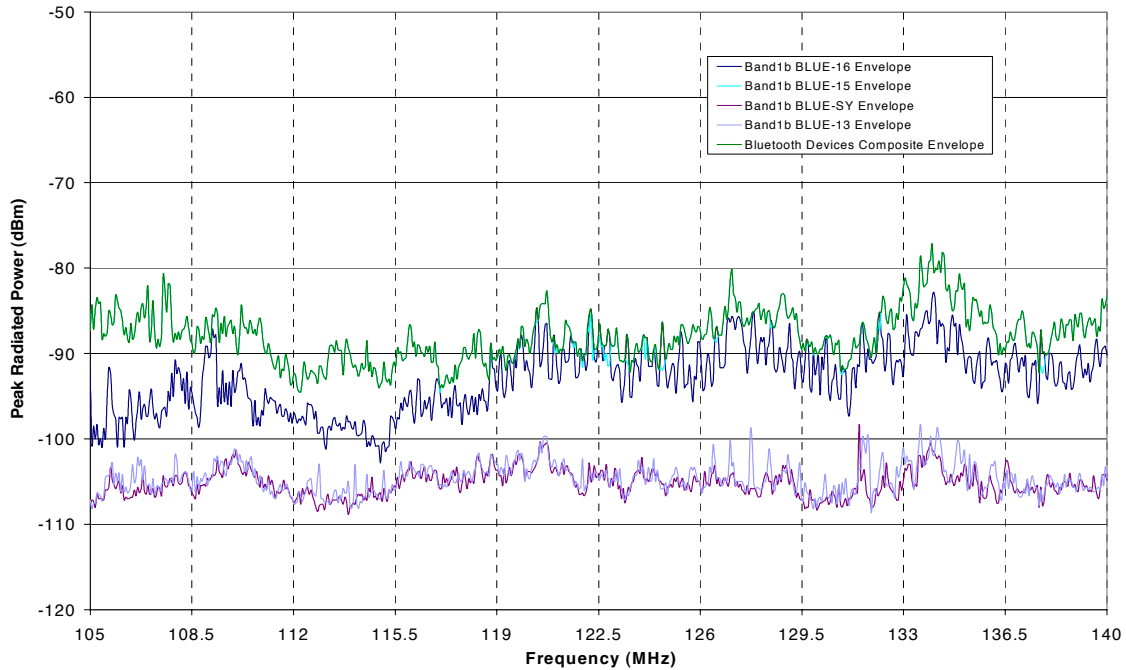


Figure 2.3-3: Individual Bluetooth WLAN Device Envelopes and Their Composite Envelope for Band 1b.

2.3.2 Band 2 (325 MHz to 340 MHz)

Data presented in Figures 2.3-4 to 2.3-6 were acquired in a measurement frequency band comprised of the ILS GS aircraft system. Individual WLAN device envelopes and a composite envelope trace including all devices in each standard are seen in the following plots.

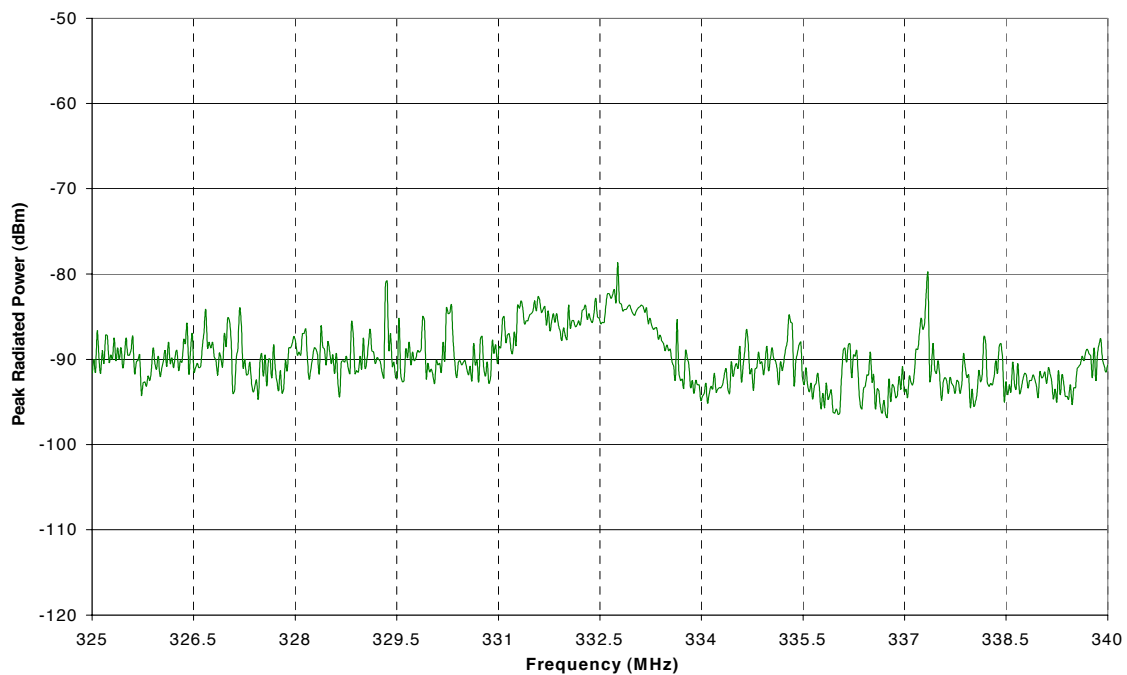


Figure 2.3-4: WLAN 802.11A-7 Device Envelope for Band 2.

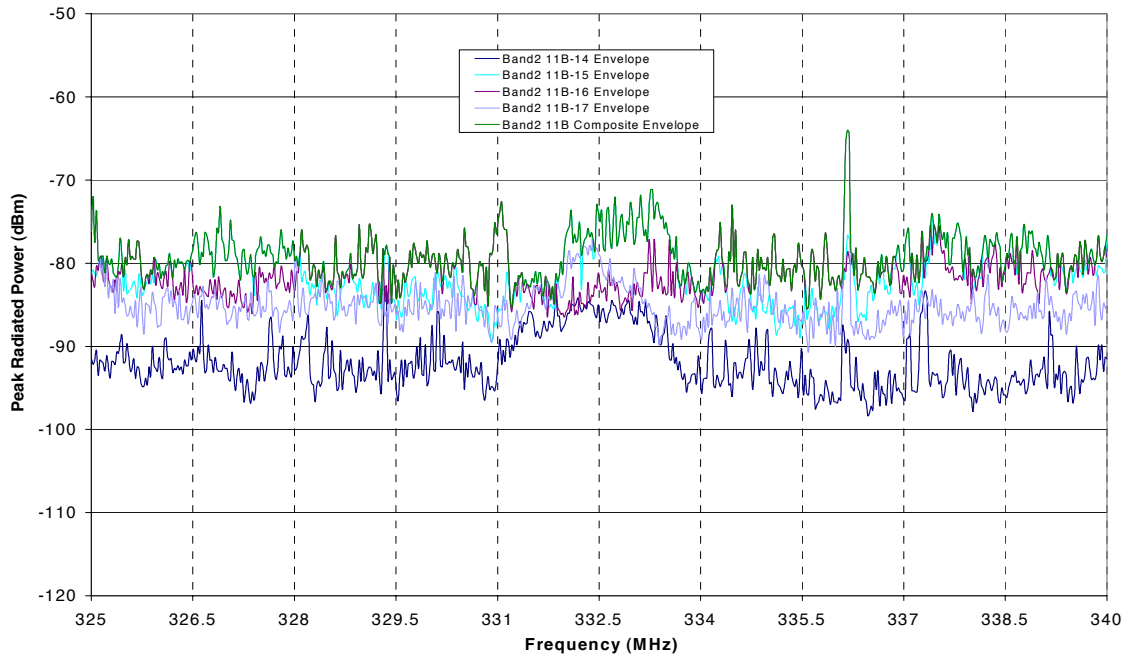


Figure 2.3-5: Individual 802.11b WLAN Device Envelopes and Their Composite Envelope for Band 2.

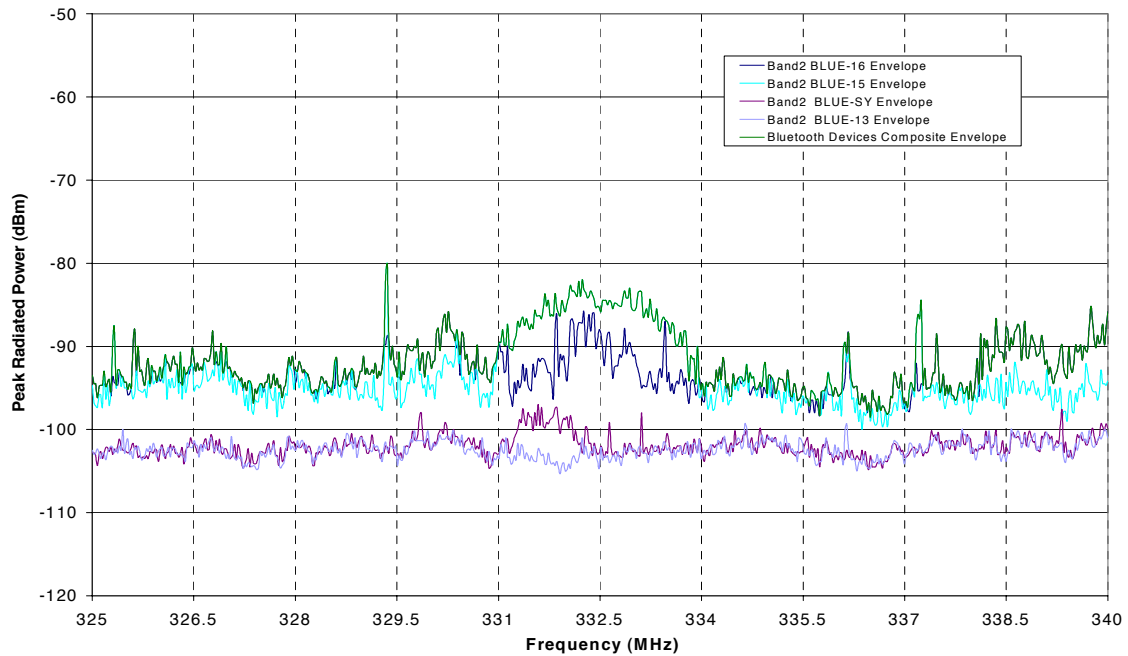


Figure 2.3-6: Individual Bluetooth WLAN Device Envelopes and Their Composite Envelope for Band 2.

2.3.3 Band 3 (960 MHz to 1250 MHz)

Data presented in Figures 2.3-7 to 2.3-9 were acquired in a measurement frequency band comprised of the TCAS, ATCRBS, DME, GPS L2, and GPS L5 aircraft systems. Individual WLAN device envelopes and a composite envelope trace including all devices in each standard are seen in the following plots.

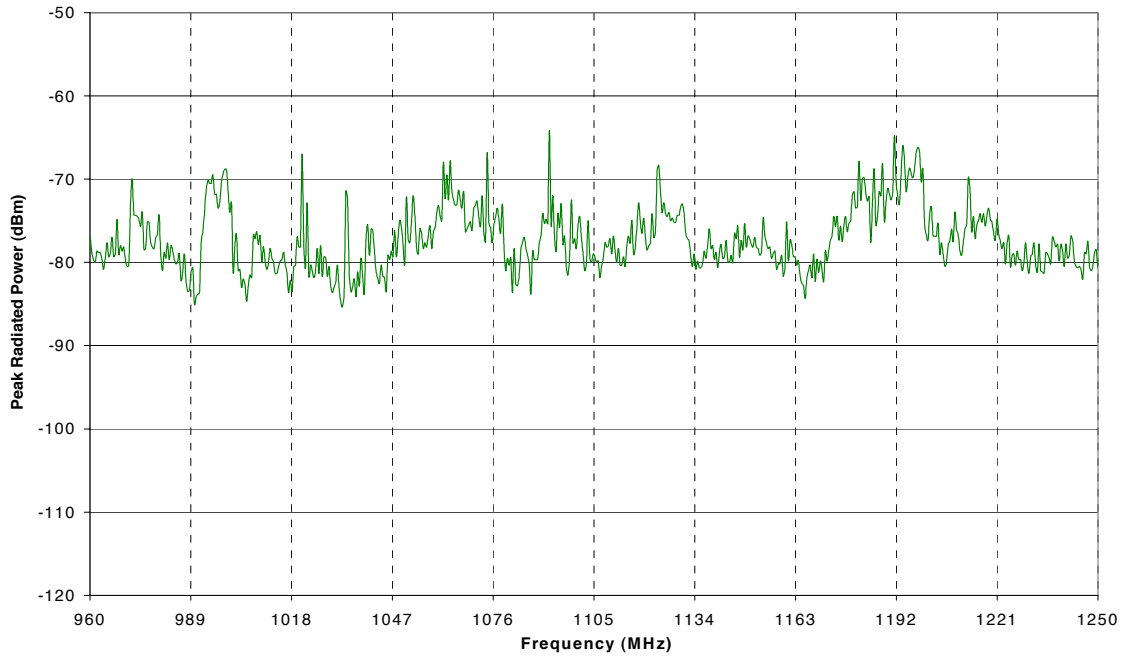


Figure 2.3-7: WLAN 802.11A-7 Device Envelope for Band 3.

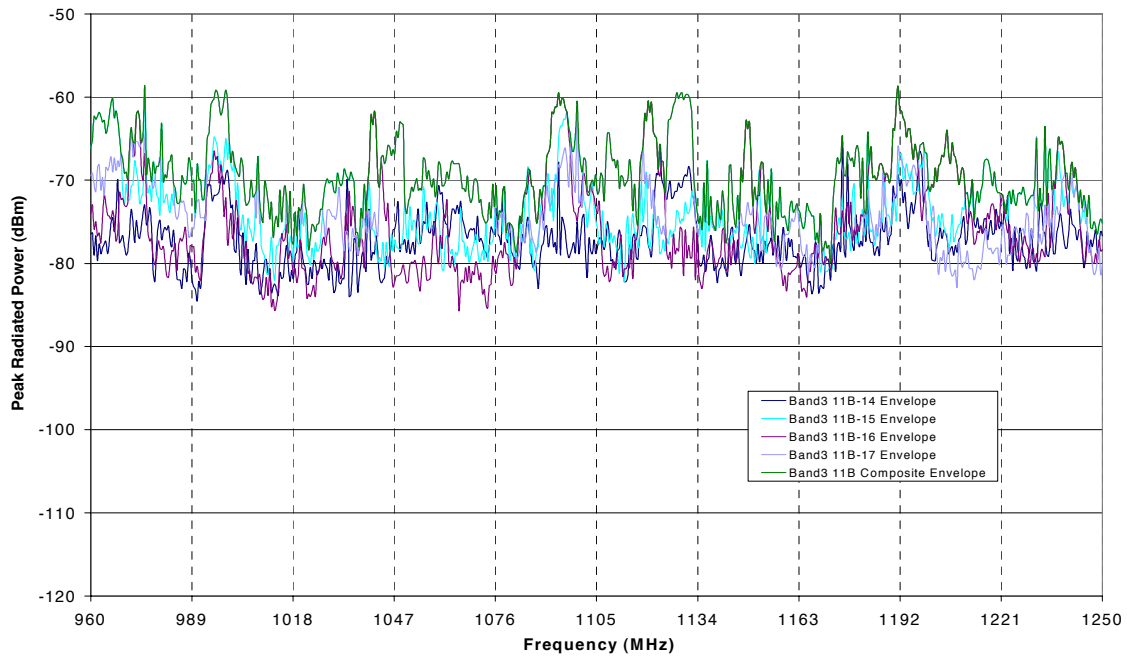


Figure 2.3-8: Individual 802.11b WLAN Device Envelopes and Their Composite Envelope for Band 3.

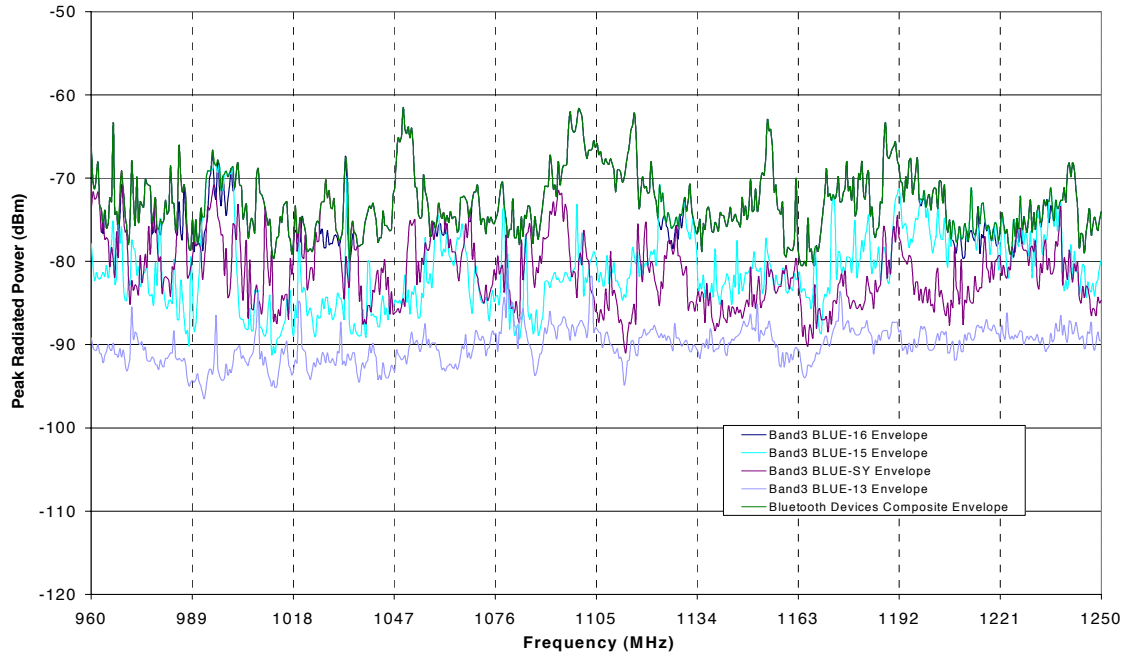


Figure 2.3-9: Individual Bluetooth WLAN Device Envelopes and Their Composite Envelope for Band 3.

2.3.4 Band 4 (1565 MHz to 1585 MHz)

Data presented in Figures 2.3-10 to 2.3-12 were acquired in a measurement frequency band comprised of the GPS L1 aircraft system. Individual WLAN device envelopes and a composite envelope trace including all devices in each standard are seen in the following plots.

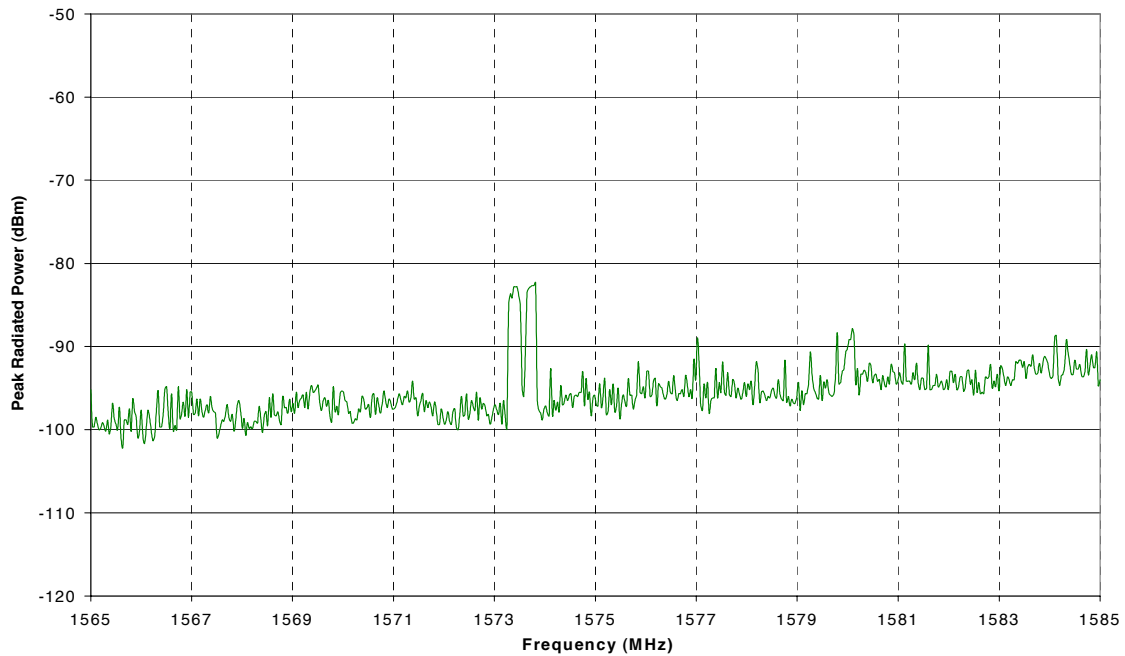


Figure 2.3-10: WLAN 802.11A-7 Device Envelope for Band 4.

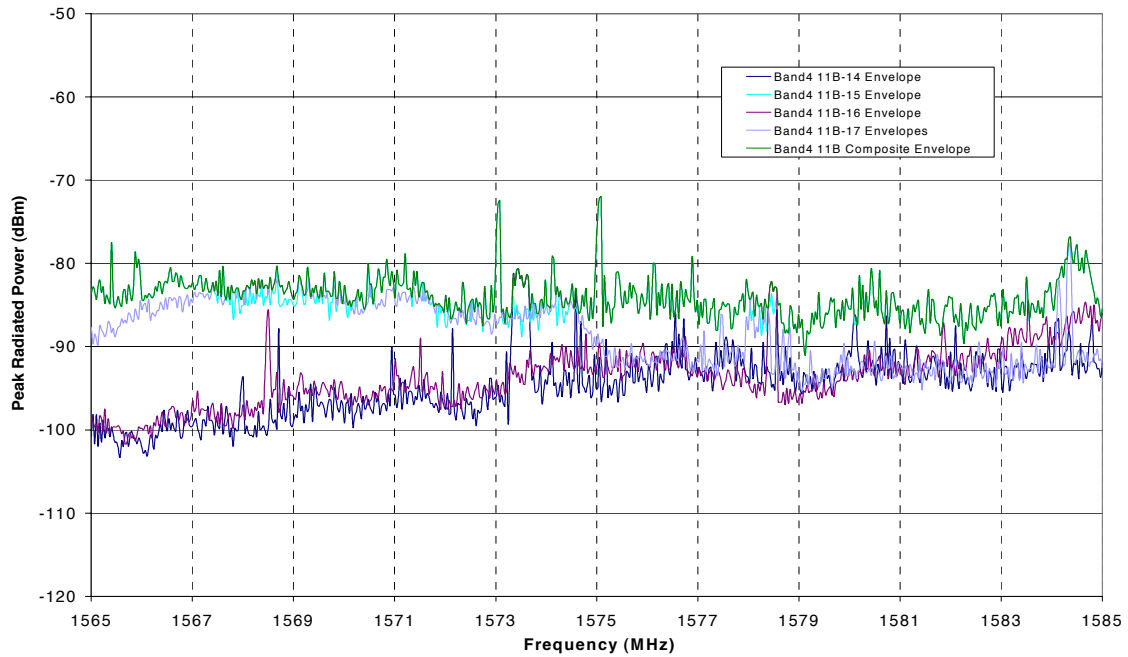


Figure 2.3-11: Individual 802.11b WLAN Device Envelopes and Their Composite Envelope for Band 4.

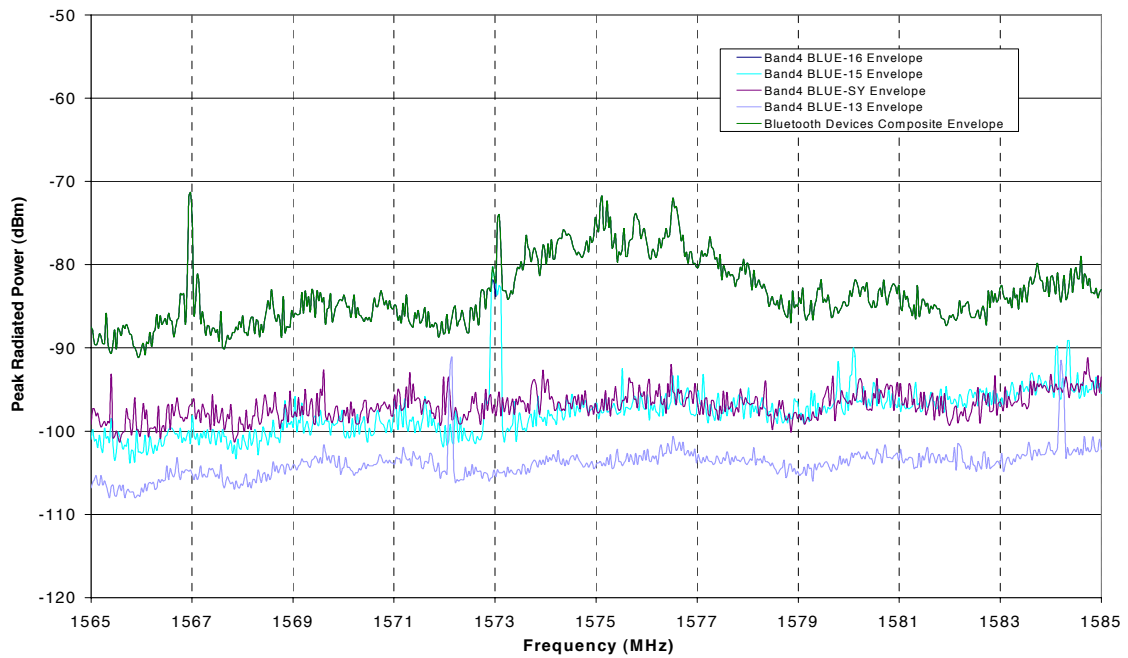


Figure 2.3-12: Individual Bluetooth WLAN Device Envelopes and Bluetooth WLAN Devices Composite Envelope for Band 4.

2.3.5 Band 5 (5020 MHz to 5100 MHz)

Data presented in Figures 2.3-13 to 2.3-15 were acquired in a measurement frequency band comprised of the MLS aircraft system. Individual WLAN device envelopes and a composite envelope trace including all devices in each standard are seen in the following plots.

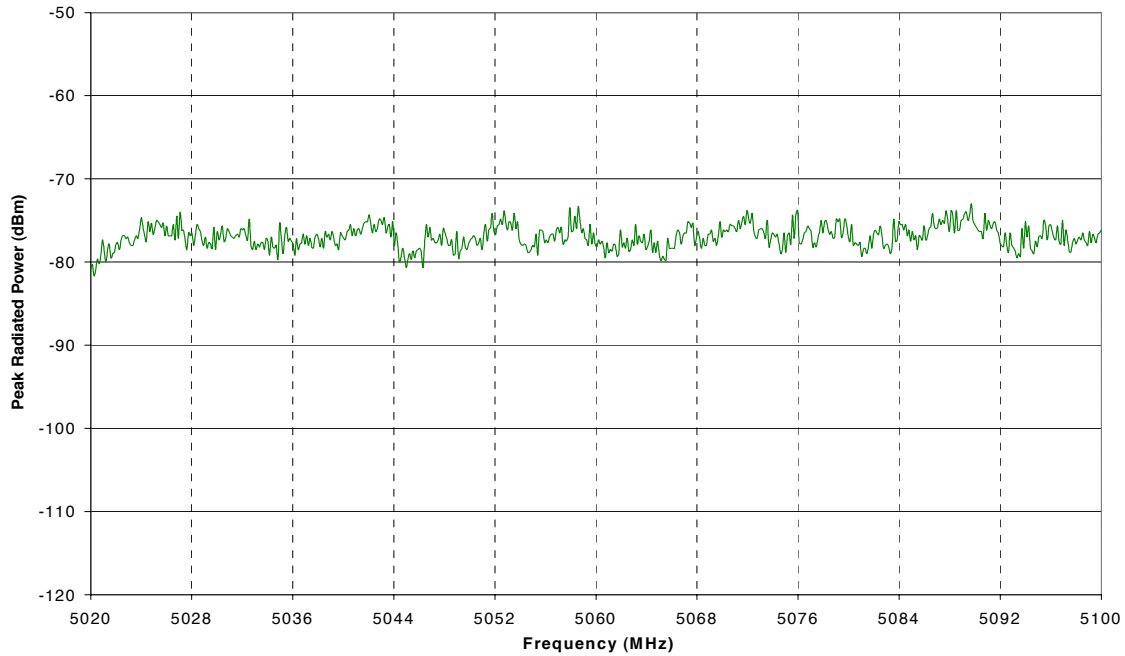


Figure 2.3-13: WLAN 802.11A-7 Device Envelope for Band 5.

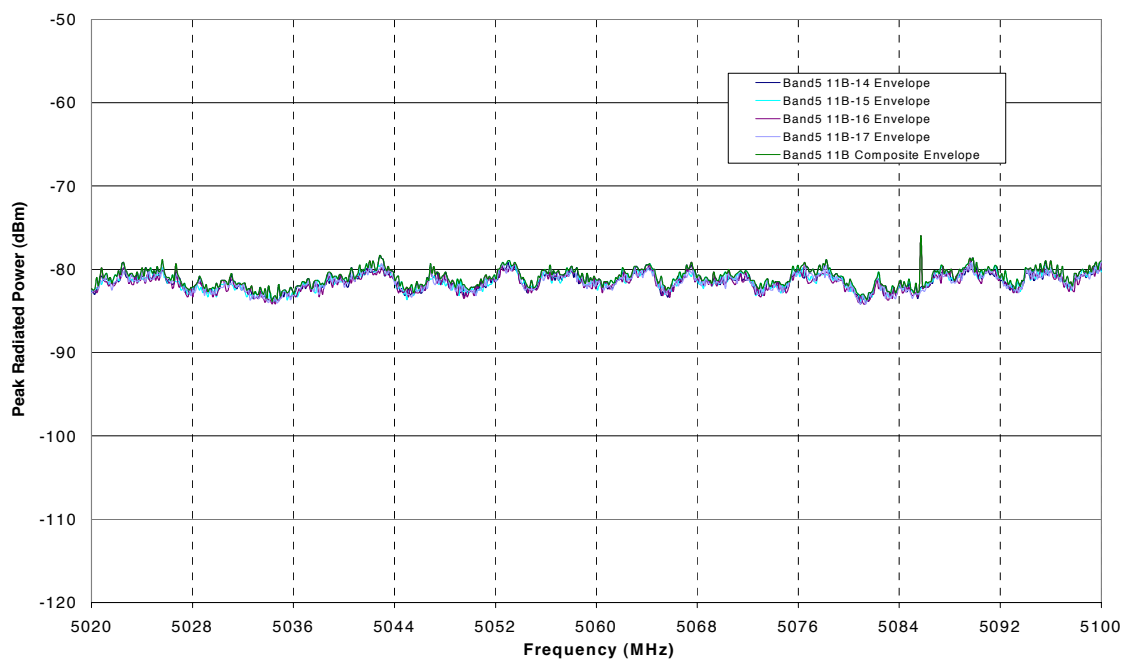


Figure 2.3-14: Individual 802.11b WLAN Device Envelopes and 802.11b WLAN Devices Composite Envelope for Band 5.

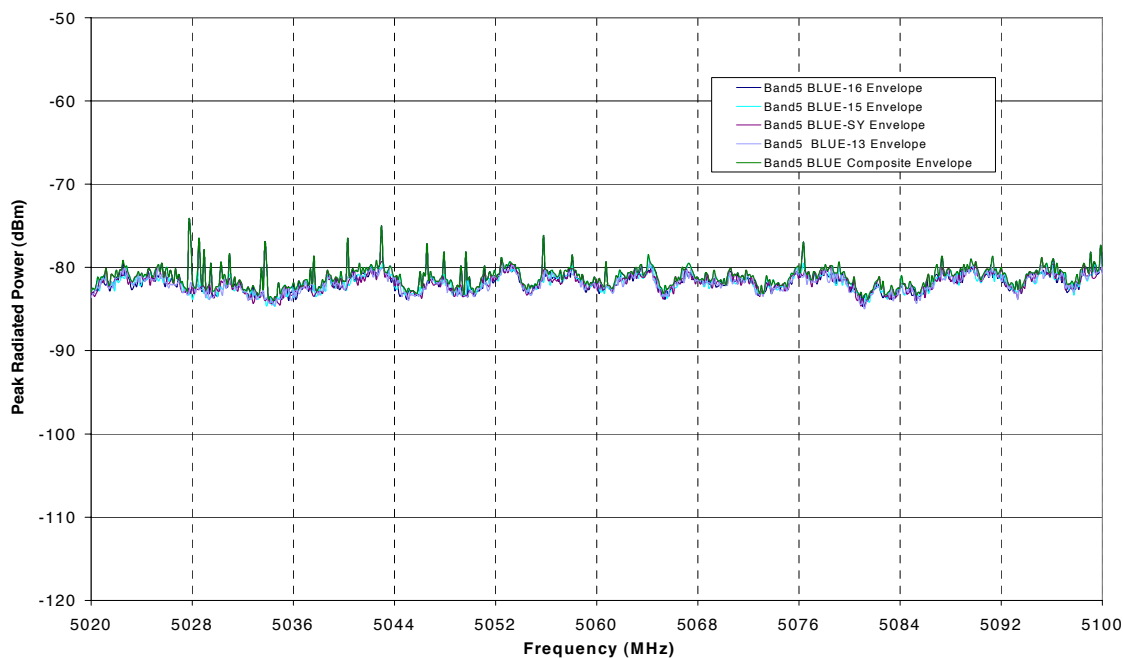


Figure 2.3-15: Individual Bluetooth WLAN Device Envelopes and Bluetooth WLAN Devices Composite Envelope for Band 5.

2.4 Laptops, Tablet PCs, and PDAs Emission Comparison

This section presents laptops, tablet PC, and PDA radiated emission results. Charts are organized and labeled according to measurement frequency band. Individual envelopes for each of the laptops, tablet PCs, and PDAs are depicted in the graphs. Each PED envelope was generated from several conducted test modes for the device (see Appendix B). A PED composite envelope trace is also included in the graph as the bold red line. The composite envelope overlays parts of or all of an individual PED envelope because it contains maximum magnitude at each frequency of all the individual PED envelopes. The PED composite envelope is compared with the WLAN composite envelope in the next section.

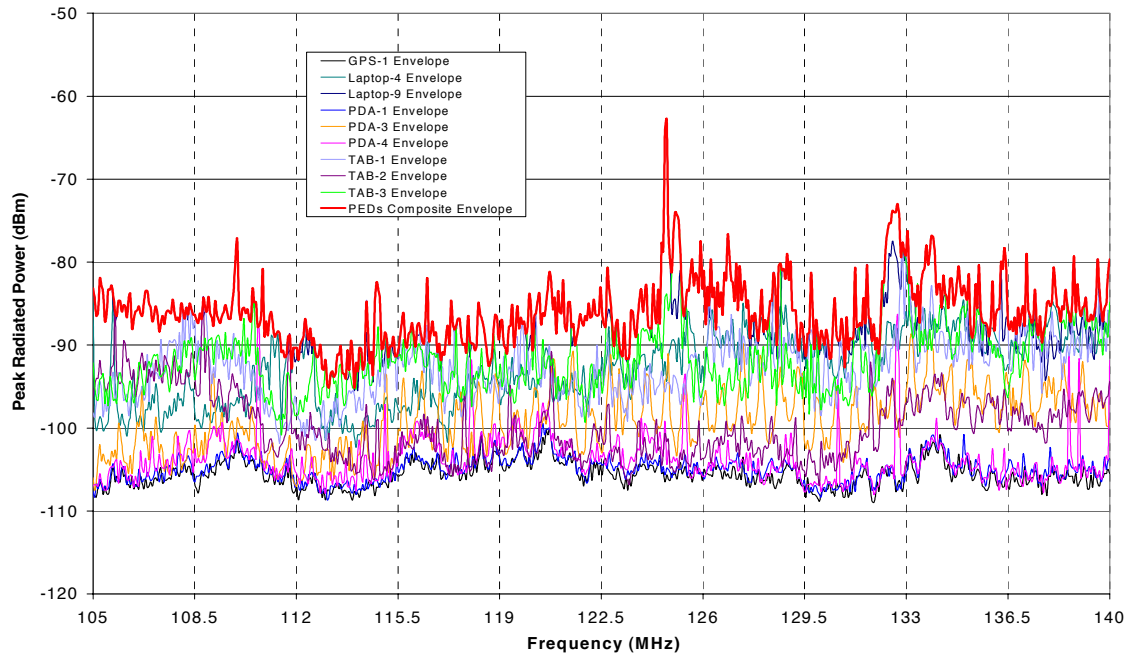


Figure 2.4-1: Individual PED Envelopes and PED Composite Envelope for Band 1b (105 MHz to 140 MHz).

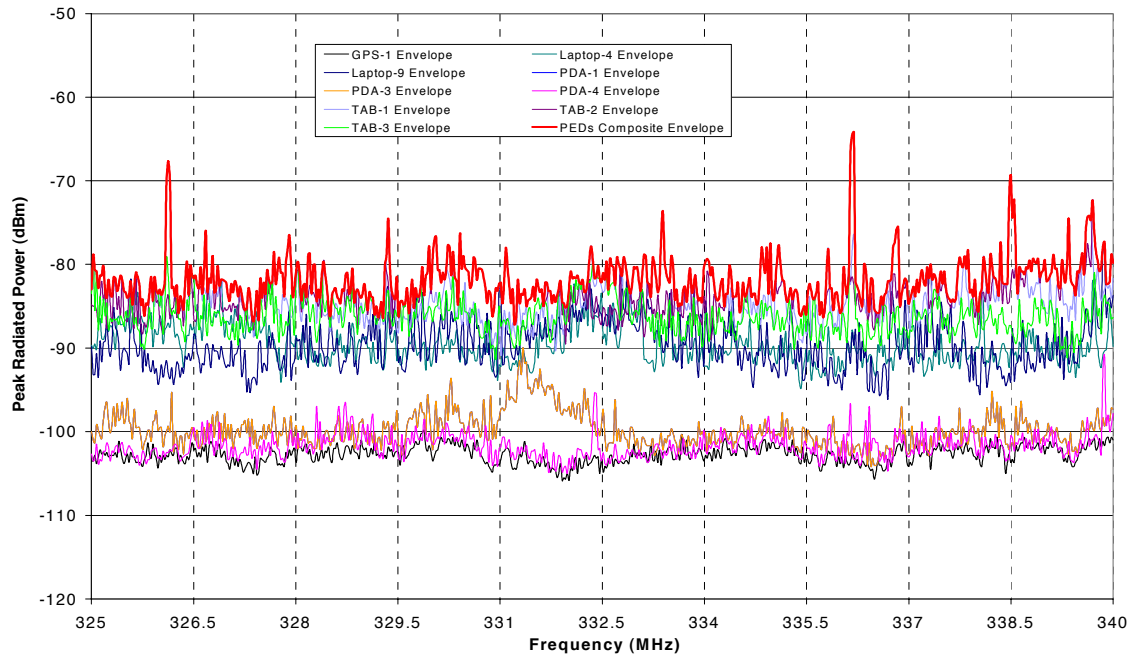


Figure 2.4-2: Individual PED Envelopes and PED Composite Envelope for Band 2 (325 MHz to 340 MHz).

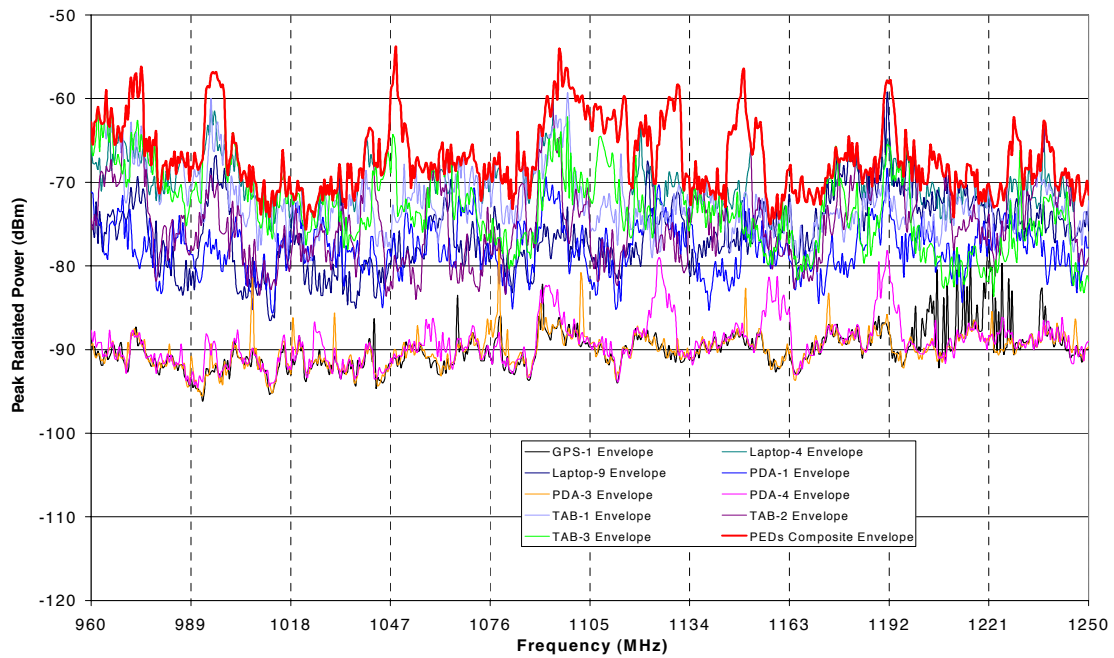


Figure 2.4-3: Individual PED Envelopes and PED Composite Envelope for Band 3 (960 MHz to 1250 MHz).

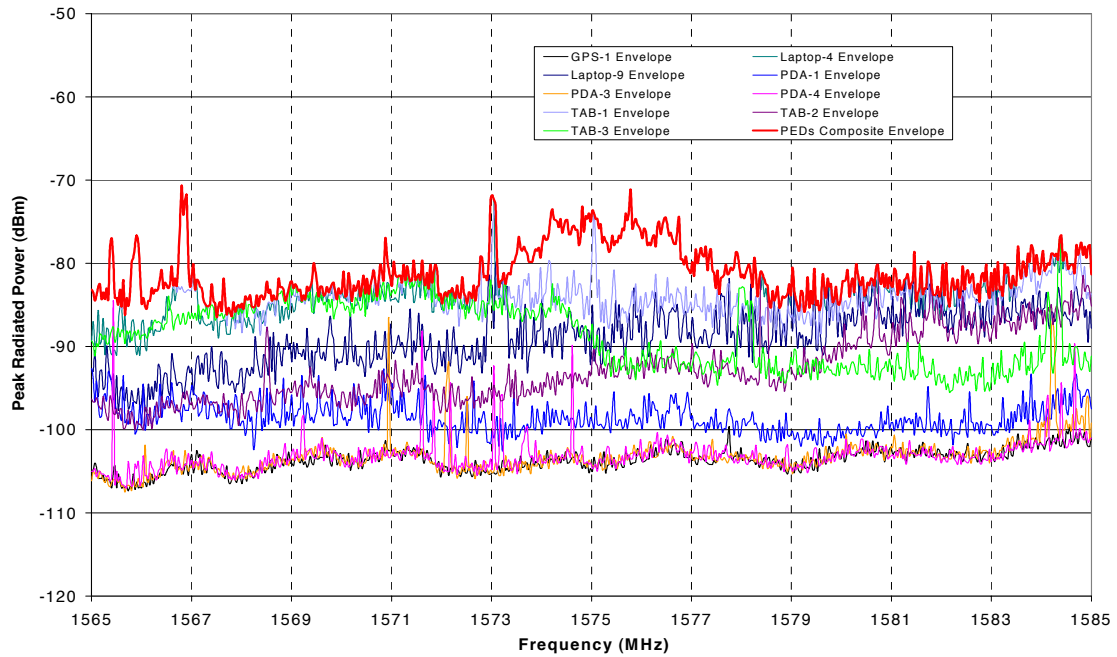


Figure 2.4-4: Individual PED Envelopes and PED Composite Envelope for Band 4 (1565 MHz to 1585 MHz).

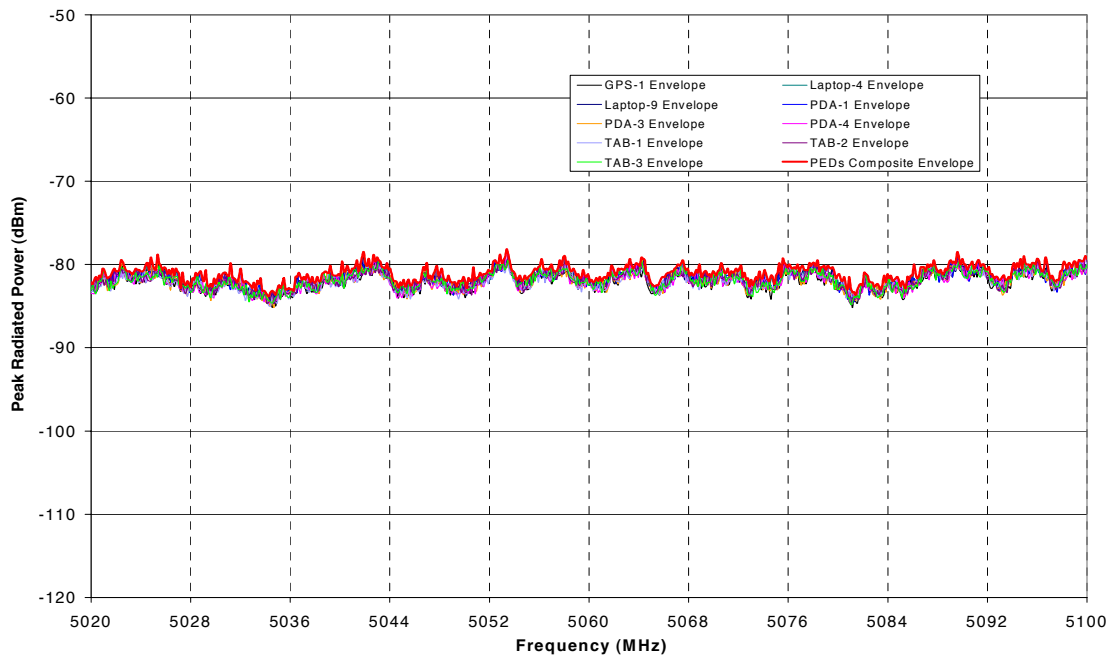


Figure 2.4-5: Individual PED Envelopes and PED Composite Envelope for Band 5 (5020 MHz to 5100 MHz).

2.5 Emission Comparison Between Intentionally and Unintentionally Transmitting PEDs

This section utilizes the WLAN devices and PED composite envelopes generated in the previous two sections to compare emissions between intentionally and unintentionally transmitting PEDs. 802.11a, 802.11b, and Bluetooth identified charts are organized according to labeled measurement frequency band sections. In the charts, a consistent bold red line from section 2.4 continues to represent the PED composite envelope and a green line consistently represents the WLAN devices' composite envelope from section 2.3.

Overall, the charts reveal that the maximum radiated spurious emissions from a group of WLAN devices are not higher than the maximum emissions from a group of PEDs. Band 5 is an exception for all three WLAN standards. The 802.11a 5.4 GHz transmission frequencies were relatively close to the measurement band causing the 802.11a envelope to be higher than the PED envelope, which was expected. 802.11b and Bluetooth also contain several sharp peaks exceeding the PED envelope.

2.5.1 Band 1b (105 MHz to 140 MHz)

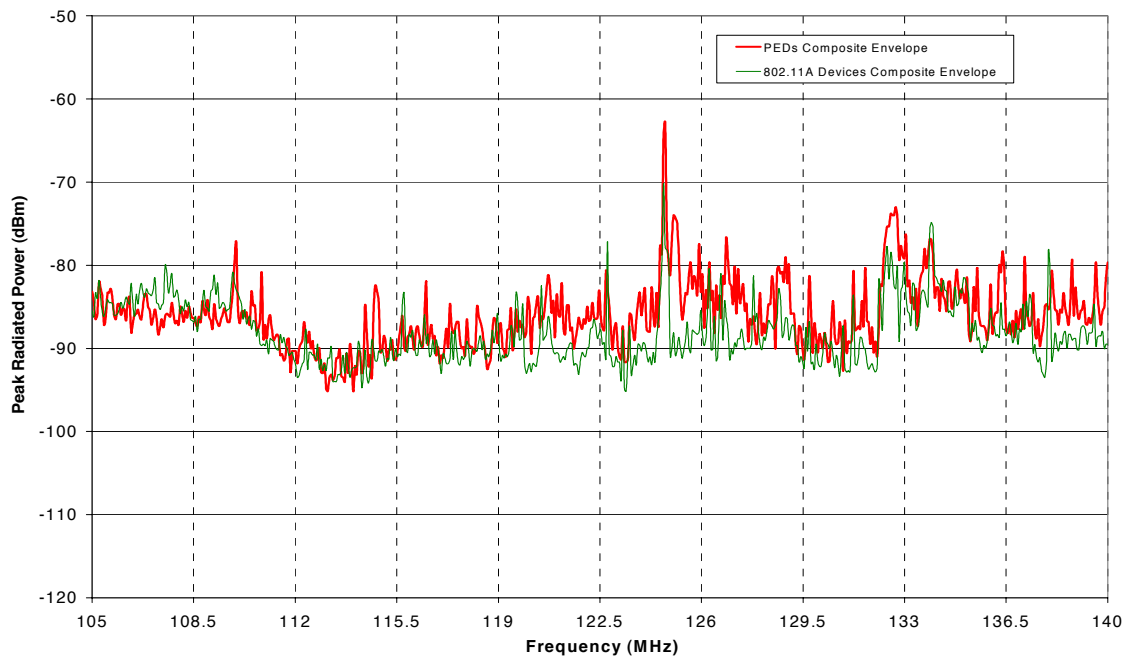


Figure 2.5-1: 802.11a WLAN Devices' Envelope and PED Composite Envelope for Band 1b.

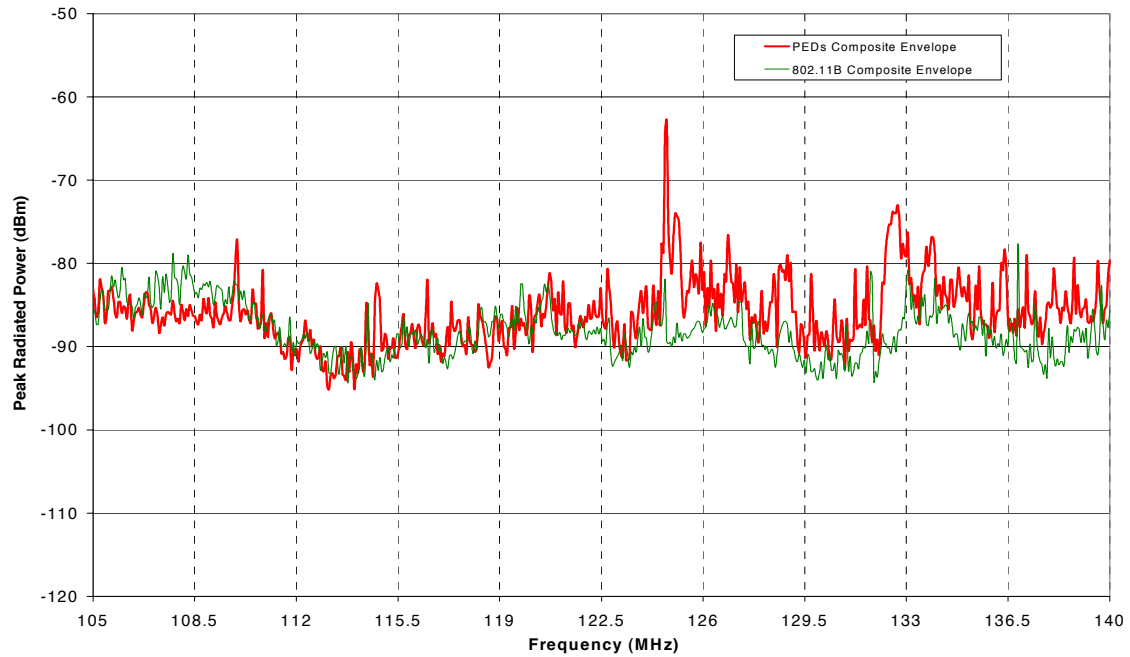


Figure 2.5-2: 802.11b Composite WLAN Devices' Envelope and PED Composite Envelope for Band 1b.

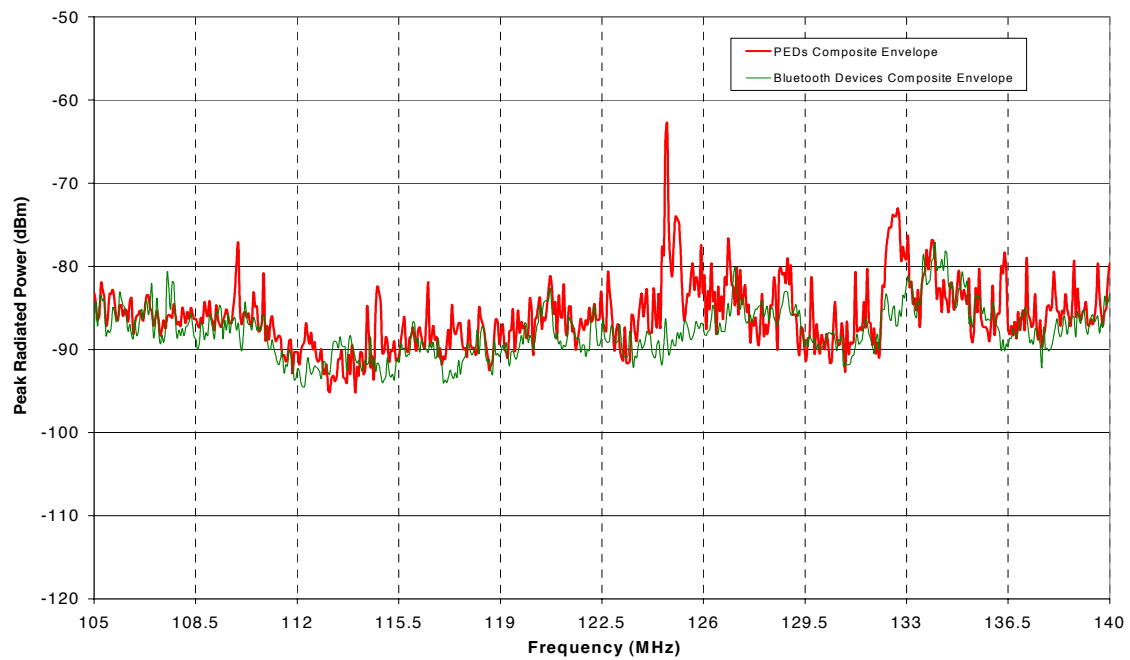


Figure 2.5-3: Bluetooth WLAN Devices' Composite Envelope and PED Composite Envelope for Band 1b.

2.5.2 Band 2 (325MHz to 340 MHz)

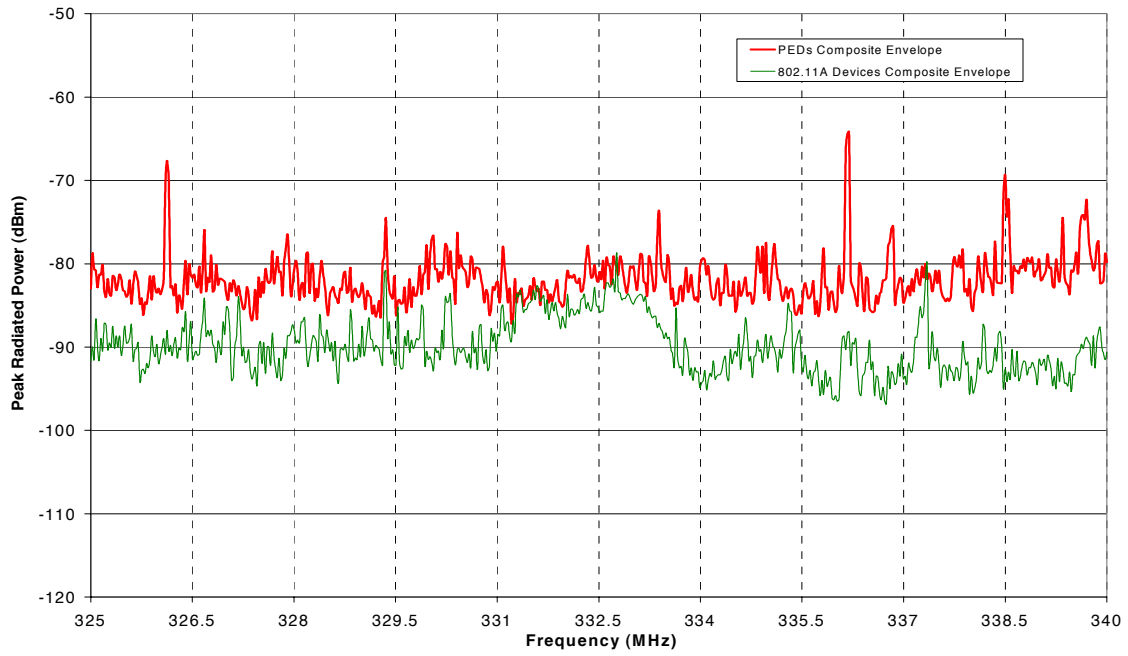


Figure 2.5-4: 802.11a WLAN Devices' Envelope and PED Composite Envelope for Band 2.

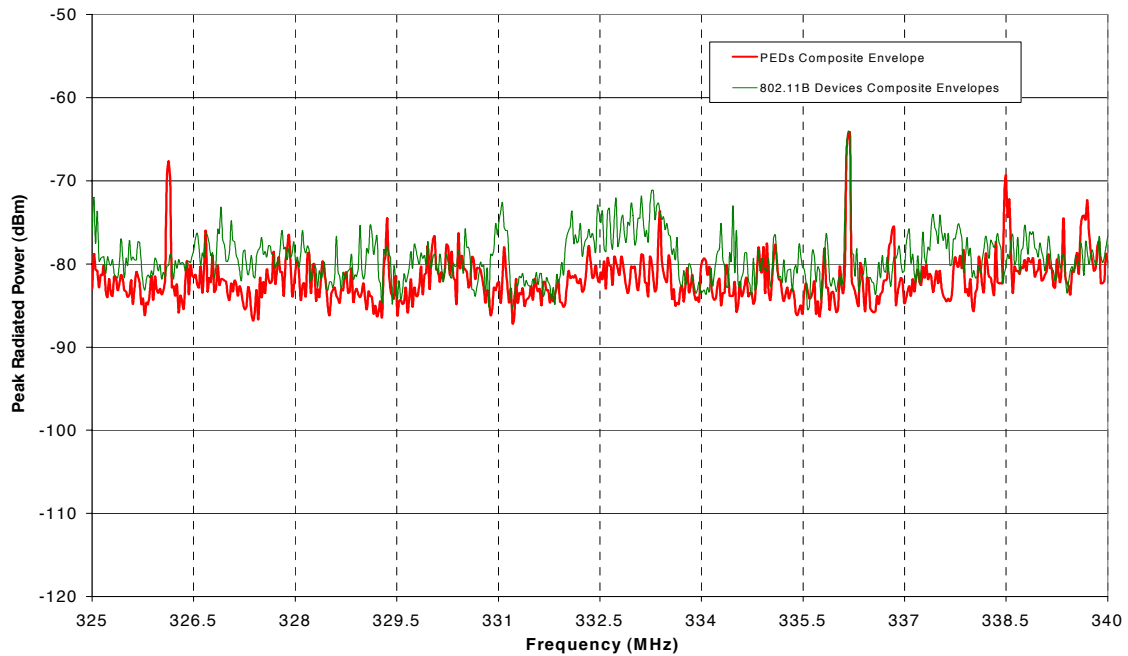


Figure 2.5-5: 802.11b Composite WLAN Devices' Envelope and PED Composite Envelope for Band 2.

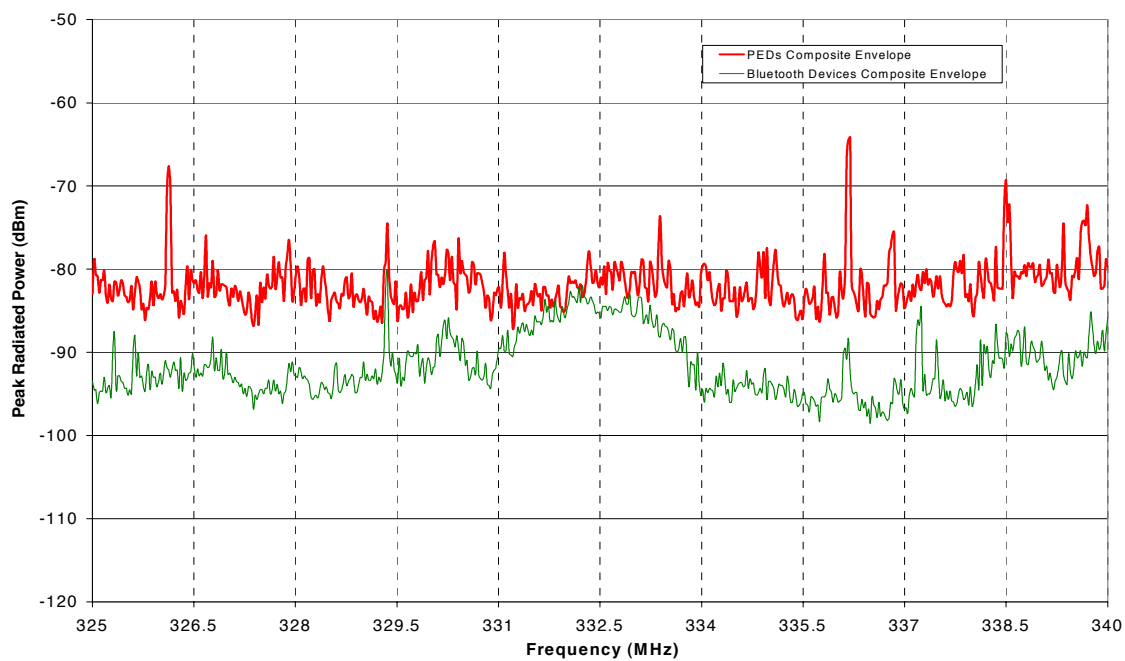


Figure 2.5-6: Bluetooth WLAN Devices' Composite Envelope and PED Composite Envelope for Band 2.

2.5.3 Band 3 (960 MHz to 1250 MHz)

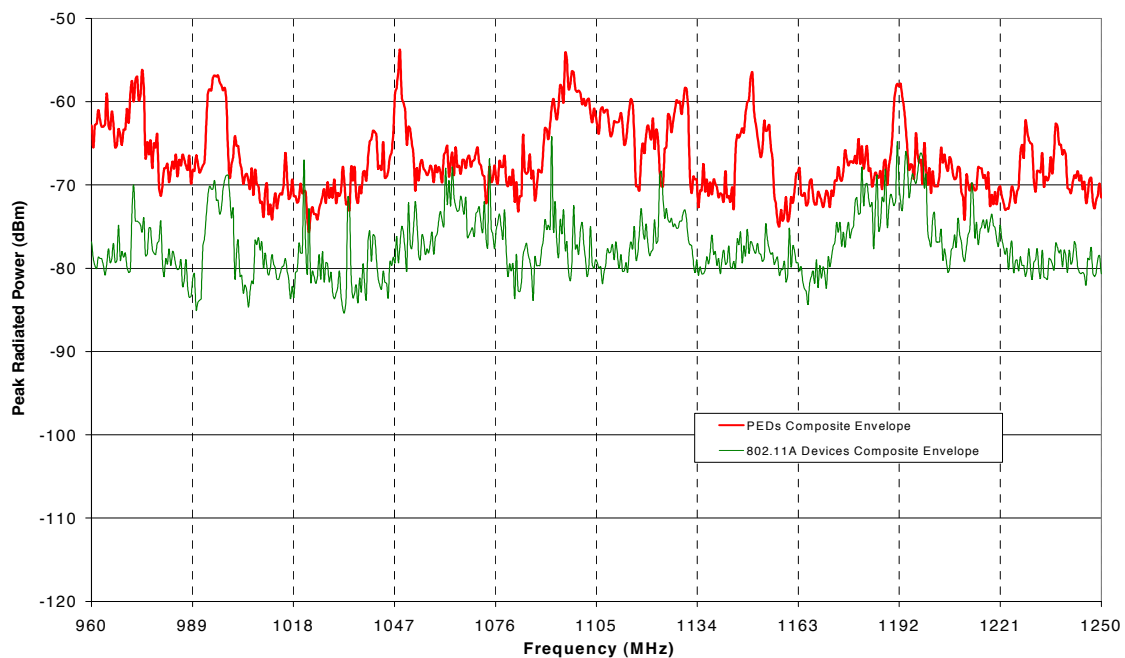


Figure 2.5-7: 802.11a WLAN Devices' Envelope and PED Composite Envelope for Band 3.

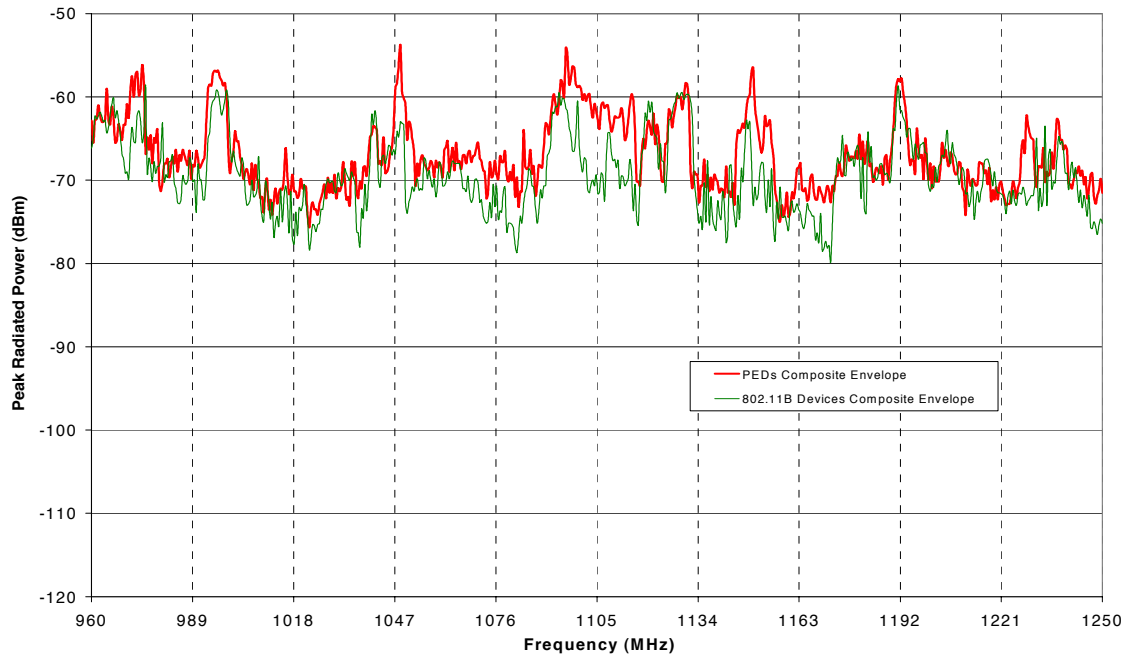


Figure 2.5-8: 802.11b Composite WLAN Devices' Envelope and PED Composite Envelope for Band 3.

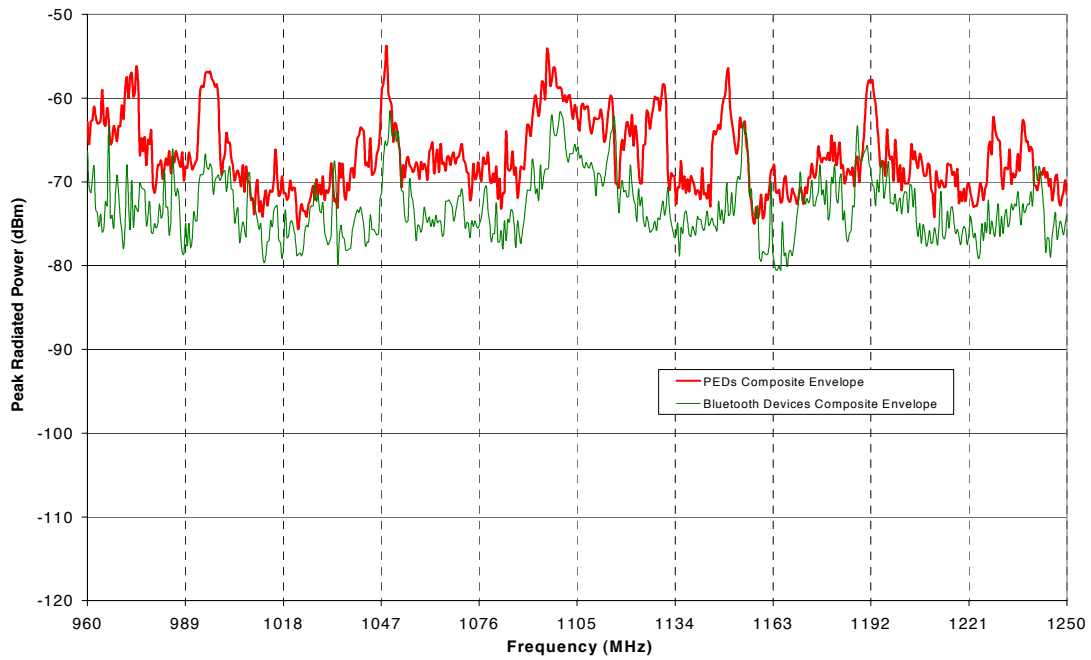


Figure 2.5-9: Bluetooth WLAN Devices' Composite Envelope and PED Composite Envelope for Band 3.

2.5.4 Band 4 (1565 MHz to 1585 MHz)

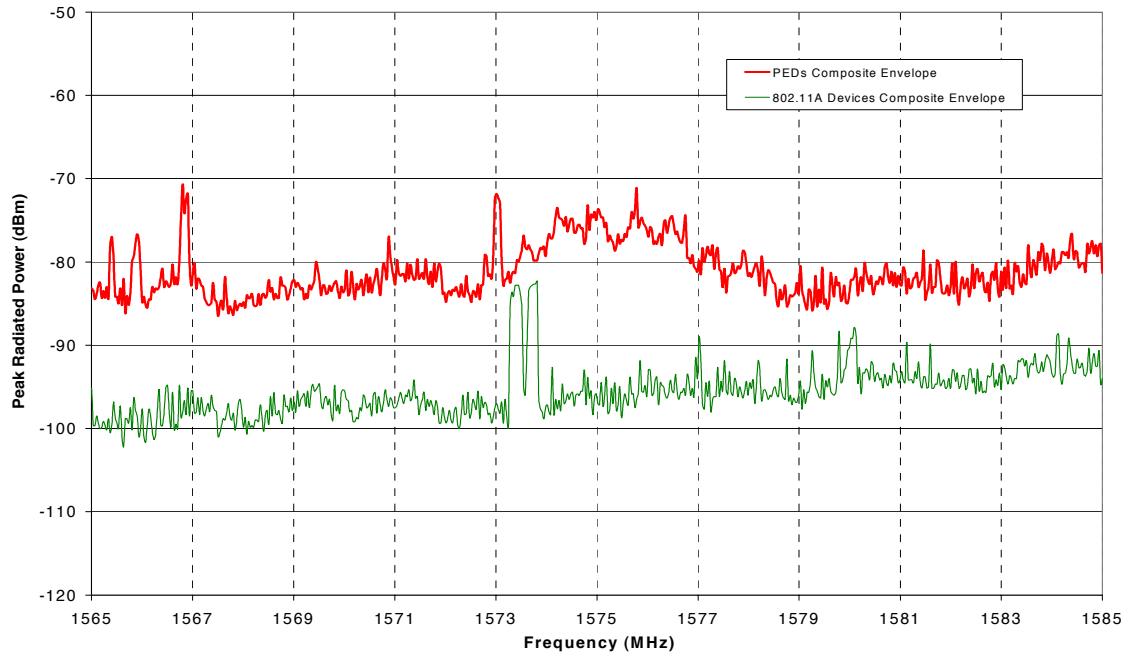


Figure 2.5-10: 802.11a WLAN Devices' Composite Envelope and PED Composite Envelope for Band 4.

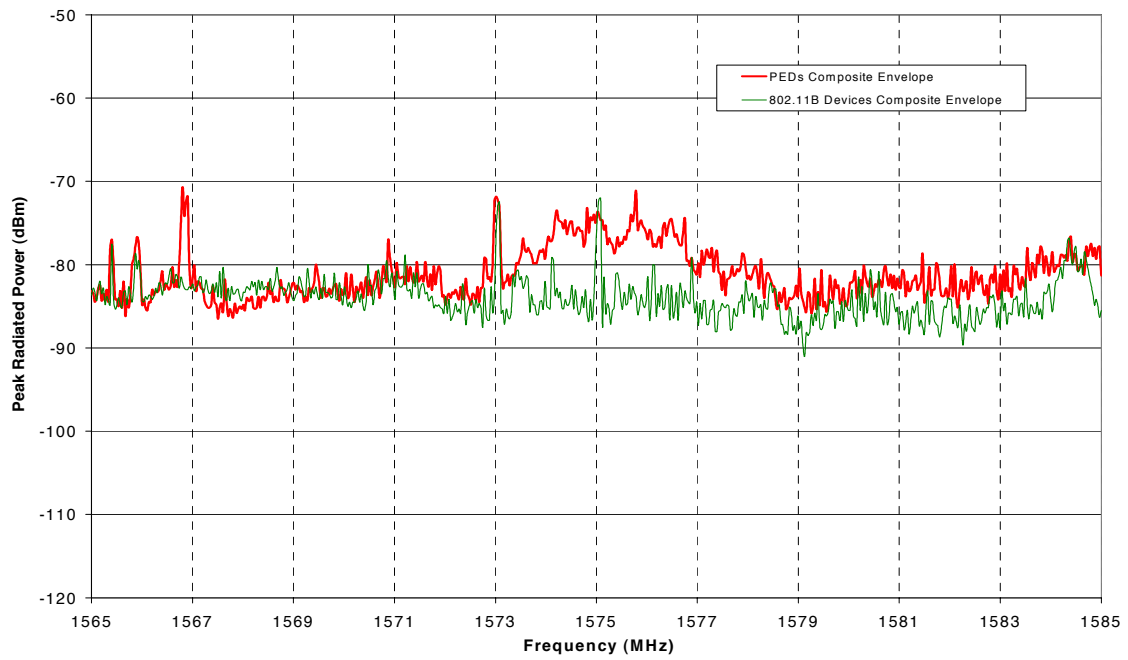


Figure 2.5-11: 802.11b Composite WLAN Devices' Envelope and PED Composite Envelope for Band 4.

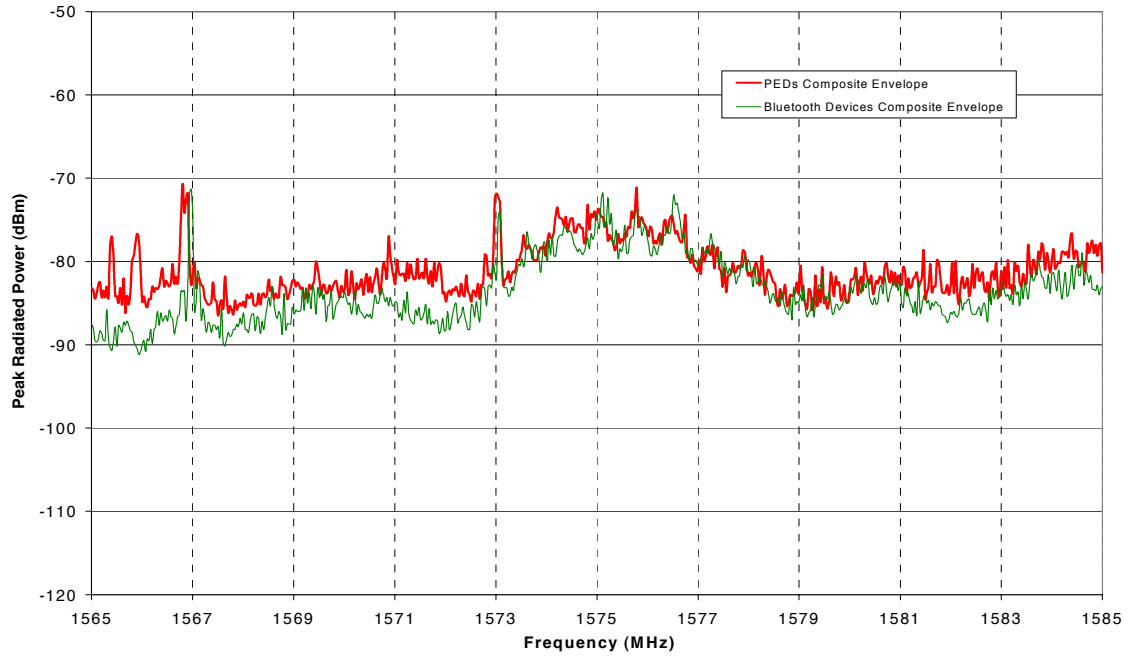


Figure 2.5-12: Bluetooth WLAN Devices' Composite Envelope and PED Composite Envelope for Band 4.

2.5.5 Band 5 (5020 MHz to 5100 MHz)

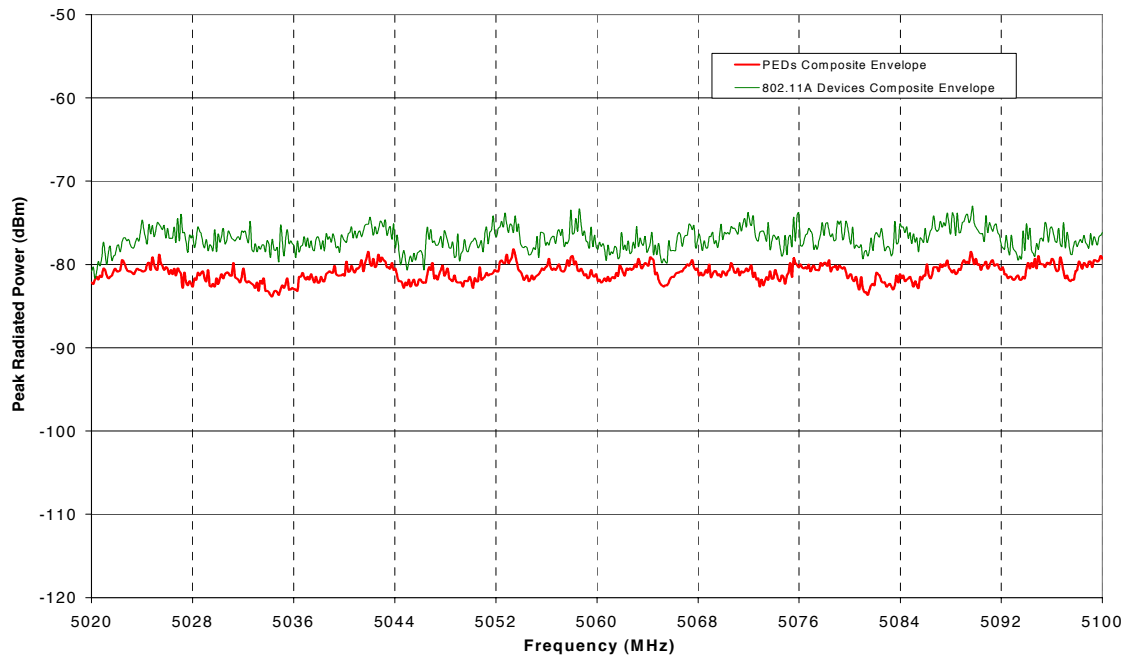


Figure 2.5-13: 802.11a WLAN Devices' Composite Envelope and PED Composite Envelope for Band 5.

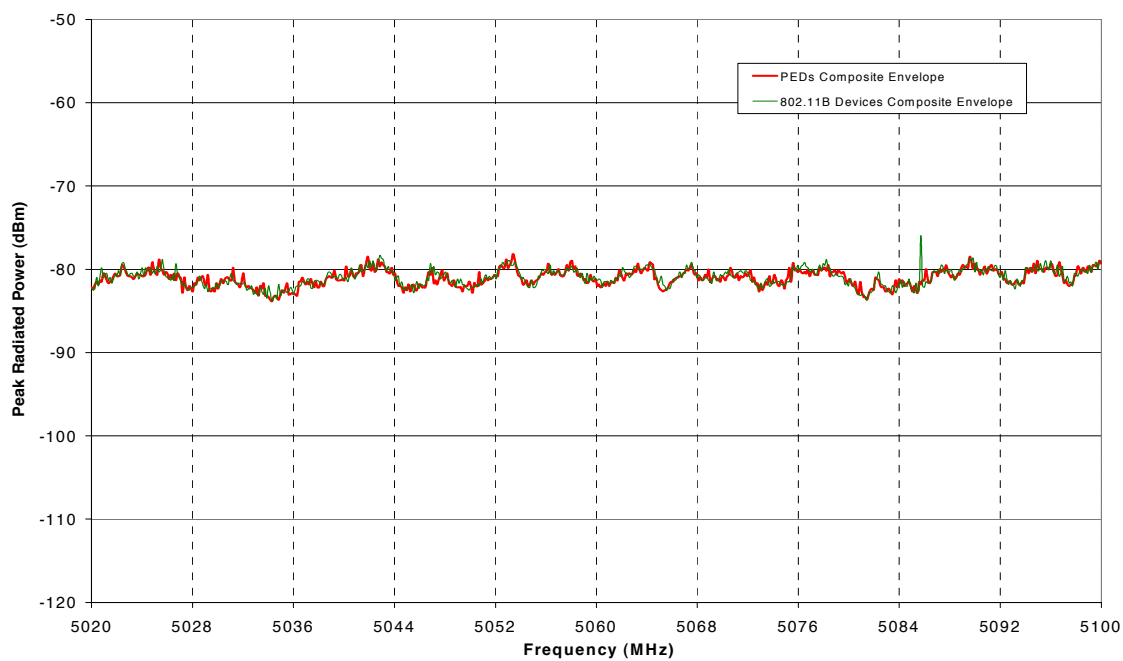


Figure 2.5-14: 802.11b WLAN Devices' Composite Envelope and PED Composite Envelope for Band 5.

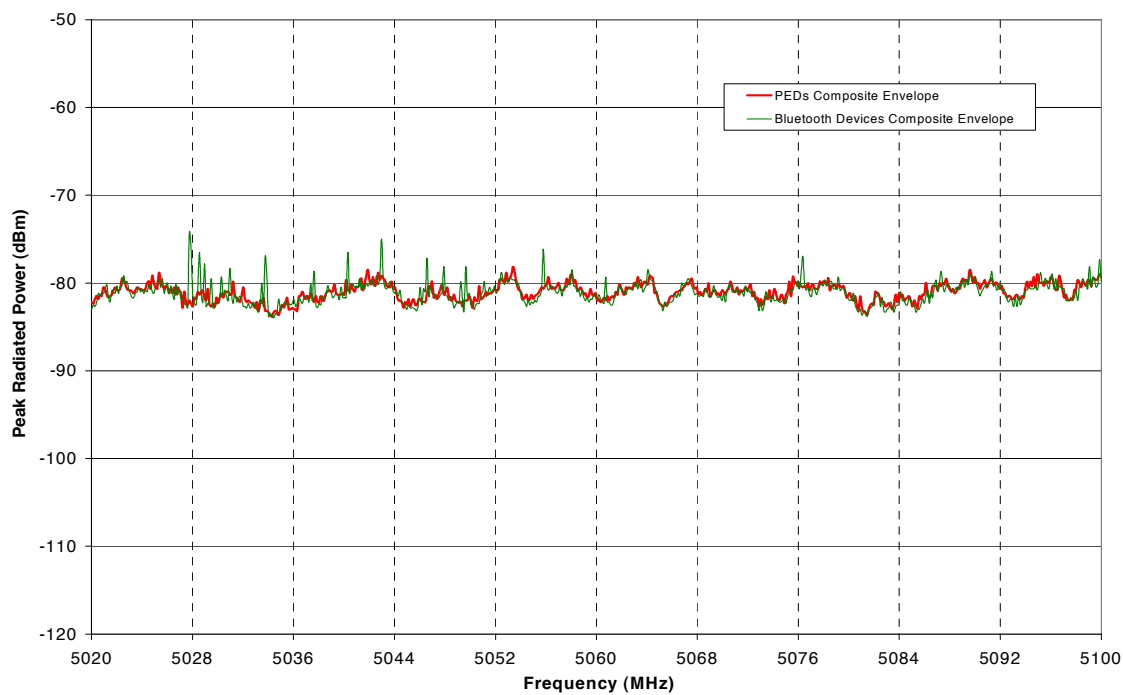


Figure 2.5-15: Bluetooth WLAN Devices' Composite Envelope and PED Composite Envelope for Band 5.

2.6 Summary of Maximum WLAN Emissions

Table 2.6-1 presents an overview of PEDs and each WLAN standard maximum emission value corresponding to each measurement band, collected from previously presented graphs. Aircraft radio-navigation systems located within the measurement bands are also shown. A potential disturbance to the aircraft system could occur if any high emission levels are present in the frequency band. This data is in line with data taken from removable WLAN PC cards and another set of PEDs [2].

Table 2.6-1: Maximum Integrated WLAN Emissions in Aircraft Bands (in dBm)

Measurement Band	Frequency (MHz)	802.11b	Bluetooth	802.11a	PEDs	Aircraft Bands
Band 1b	105 - 140	-77.7	-77.2	-70.1	-62.8	LOC, VOR, VHF
Band 2	325 - 340	-64.3	-80.2	-78.7	-64.2	GS
Band 3	960 - 1250	-58.7	-61.5	-64.2	-53.8	TCAS, ATC, DME/TACAN, GPS L2
Band 4	1565 - 1585	-72.0	-71.3	-82.3	-70.7	GPS L1
Band 5	5020 - 5100	-76.0	-74.3	-73.0	-78.2	MLS

Figure 2.6-1 graphically depicts emission values from Table 2.6-1. (Note: The lines in Figure 2.6-1 simply connect the data points at each marker. There is no significance to the magnitude values.) Notice all the bands, with the exception of Band 5, demonstrate that laptop/tablet PCs/PDAs have higher emissions during normal operations as an unintentional transmitter than when the WLAN device is turned on converting the PED to an intentional transmitter. In Band 5, 802.11b and Bluetooth had some spikes across the measurement band caused by devices 11B-16 and BLUE-16 (refer to the graphs in section 2.5). High emissions from an 802.11a device was not unexpected, since the proximity of the 802.11a transmission frequency band and Band 5 are close in the 5 GHz range. MLS interference probability is small because they are seldom installed on airplanes in the U.S.

PEDs and WLAN devices emissions data in Band 5 are not any higher than 5 dBm above the measurement noise floor as indicated by the data collected near -78 dBm.

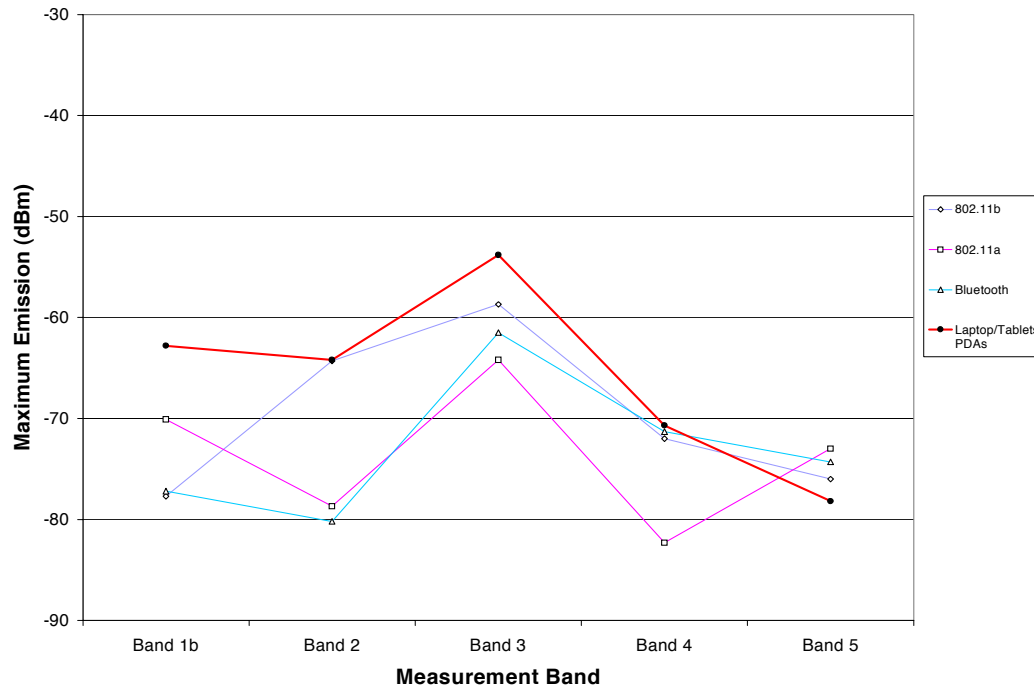


Figure 2.6-1: Maximum emission from WLAN, Bluetooth devices, and Laptop/Tablets/PDAs.

2.6.1 Emission Limits

Table 2.6-2 provides emission limits for the measurement frequency bands set forth by regulatory organizations. The Federal Communication Commission (FCC) mandated emission limits for unintentional and intentional radiators are described further in their document under Part 15.109 [7] and Part 15.209 [8]. The FAA has considered the RTCA/DO-160 Category M emission limit [9] documentation and recommends that airlines heed this collected information about passenger carry-on electronic devices located in the passenger cabin or the cockpit of a transport aircraft where electromagnetically significant apertures (windows) reside.

Category M:

“This category is defined for equipment and interconnected wiring located in areas where apertures are em significant and not directly in view of radio receiver’s antenna. This category may be suitable for equipment and associated interconnecting wiring located in the passenger cabin or in the cockpit of a transport aircraft.”

Limit values listed in Table 2.6-2 RTCA/DO-160 Category M limit column provide the lowest limit among the aircraft bands occupying each measurement band. Band 3 encompasses TCAS, ATCRBS, DME, GPS L2 and GPS L5, which support the previous statement. Both GPS L2 and GPS L5 have higher limits, therefore the lowest value is provided by TCAS, ATCRBS and DME at 50dBμV/m.

FCC Part 15 field strength limits and RTCA/DO-160 Category M are converted to the equivalent Effective Isotropic Radiated Power (EIRP) using Equation 2.6-1; and the resulting units are in watts. The mathematical expression $10 * \log(1000 * EIRP)$ converts power, EIRP, from watts to dBm. Units for RTCA/DO-160 limits had to be converted from dBμV/m to V/m before applying Equation 2.6-1.

$$EIRP = \frac{E^2 \cdot 4\pi R^2}{120\pi} \quad (\text{Eq.2.6-1})$$

where $EIRP$ = Effective Isotropic Radiated Power (W)
 E = Electric Field Intensity at distance R (V/m)
 R = Distance (m)

Table 2.6-2: FCC and RTCA Estimated EIRP Limits

	FCC Part 15 Limit ($\mu\text{V/m}$ @ 3m)	RTCA/DO-160 Category M Limit (dB $\mu\text{V/m}$ @ 1m)	FCC Part 15 Limit (EIRP, dBm)	RTCA/DO-160 Category M Limit (EIRP, dBm)
Band 1	150	35	-51.7	-69.8
Band 2	200	52.9	-49.2	-51.9
Band 3	500	50	-41.2	-54.8
Band 4	500	53	-41.2	-51.8
Band 5	500	71.8	-41.2	-33.0

Once regulatory emission limits are converted to the proper units, a comparison can be made with measured emission data collected utilizing a RC. Before the comparison can be made, directivity gain from the DUT has to be considered. A RC produces measurement results in the form of “total radiated power” (TRP) within the measurement resolution bandwidth. TRP is equivalent to EIRP only if an antenna or device has an isotropic radiated pattern. Otherwise,

$$EIRP \text{ (dBm)} = TRP \text{ (dBm)} + D_G \text{ (dB)} \quad (\text{Eq. 2.6-2})$$

where D_G is directivity, or maximum directivity gain of the test device. Directive gain is a measure of radiated power in a given direction referenced to an isotropic antenna.

In order to compare EIRP and TRP values, directivity is essential in describing the spurious emissions from test objects in RCs. However, D_G is difficult to measure or calculate because the maximum radiation angles and electrical arrangement of components for spurious emissions are unknown. Directive gain measurements are typically collected over an entire sphere surrounding the device to determine the direction and value of the maximum directive gain. A NIST study was performed to determine various methods to statistically estimate D_G of the test object based on electrical size [10]. These methods have yet to be validated or accepted.

Unity D_G was assumed for WLAN devices’ spurious emissions to simplify the following comparison between limits and emission data. At this point, TRP is assumed to be equivalent to EIRP for all measurement frequency bands. However by assuming unity, uncertainty is introduced into Eq. 2.6-2. For an electrically small dipole antenna the D_G is approximately 1.76 dBi (relative to isotropic). D_G is approximately 2.15 dBi for a half-wave dipole. Hence, an expected level of uncertainty should be in the vicinity of 2-5 dB where devices are up to one-half a wavelength in size.

Figure 2.6-2 depicts a graphical illustration of emissions from laptop/tablets/PDAs and WLAN devices as compared to regulatory limits. WLAN devices and laptop/tablets/PDAs are well below the FCC spurious emission limit. Whereas, WLAN devices are considerably lower than the RTCA/DO-160 limits, except in the case of Band 1b, where 802.11a meets the limit within tenths of a dB. In Band 1b and Band 3, laptop/tablets/PDAs exceed the RTCA/DO-160 Category M limits. Yet, WLAN devices' emissions are lower than laptop/tablets/PDAs except in Band 5. This study shows that integrated WLAN devices should not compromise the integrity of aircraft radio systems any more than those emissions from laptop/tablets/PDAs. Note that this is only a first order comparison, since directivity is not yet accounted for in the emission measurements.

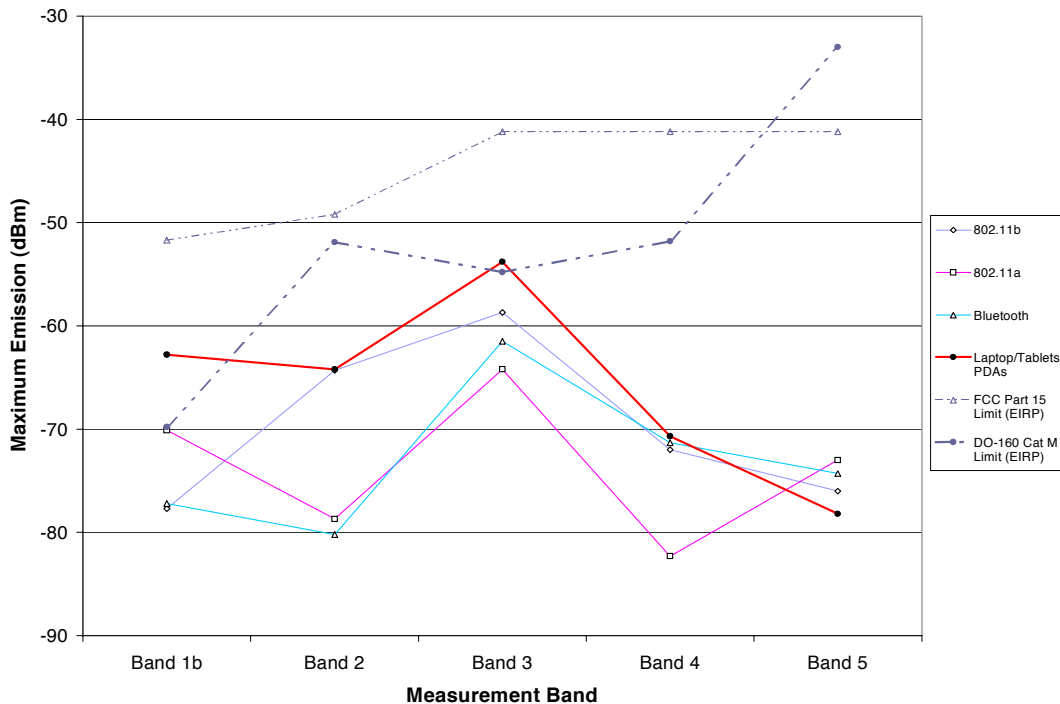


Figure 2.6-2: Maximum Emission from three WLAN standards and Laptop/Tablets/PDAs compared to FCC and RTCA EIRP limits.

3 Conclusions

Maximum spurious emission measurements conducted on a group of WLAN devices are not any higher than the maximum spurious emissions from tested PEDs in the considered aircraft com/nav bands. The MLS band was the exception where WLAN devices emission levels were higher than PEDs emissions. Since there is a large safety margin in Band 5, WLAN devices are not a concern. Integrated WLAN device emissions remained lower than FCC and RTCA/DO-16 Category M limits. Although laptop/tablets/PDAs emissions can be higher than RTCA/DO-160 Category M limits, they are lower than their intended FCC spurious emission limit.

Further tests should be conducted using the 802.11a device standard. Since only one device was tested, there was an incomplete sampling of devices. Additionally, test time may be reduced if channel switching does not have an effect on spurious emissions data.

4 References

- [1] FAA, *Use of Portable Electronic Devices Aboard Aircraft – FAA AC 91.21-1* <http://www1.faa.gov/avr/afs/acs/ac91211a.pdf>
- [2] Nguyen, T. X.; Koppen, S. V.; Ely, J. J.; Williams, R. A.; Smith, L. J.; and Salud, M. P.: *Portable Wireless LAN Device and Two-Way Radio Threat Assessment for Aircraft Navigation Radios*, NASA Technical Paper TP-2003-212438, July 2003.
- [3] Ladbury, J.; Koepke, G.; and Camell, D.: *Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility*, NIST Technical Note 1508, January 1998.
- [4] Crawford, M. L.; and Koepke, G.H.; *Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements*, NBS Technical Note 1092, U.S. Department of Commerce/National Bureau of Standards, April 1986.
- [5] International Electrotechnical Commission (IEC) 61000-4-21, 2003 Draft.
- [6] Koppen, S. V., *A Description of the Software Element of the NASA Portable Electronic Device Radiated Emissions Investigation*, NASA Contractor Report CR-2002-211675, May 2003.
- [7] 47CFR Ch. 1, Part 15.109, “Radiated Emission Limits”, *US Code of Federal Regulations*, Federal Register dated December 19, 2001.
- [8] 47CFR Ch. 1, Part 15.109, “Radiated Emission Limits; General Requirements”, *US Code of Federal Regulations*, Federal Register dated December 19, 2001.
- [9] RTCA DO-160D, Change No. 1, Section 21, “Emission of Radio Frequency Energy”, *Environmental Conditions and Test Procedures for Airborne Equipment*, Prepared by SC-135, December 14, 2000.

Appendix A: Graphical Measurement Results of Intentional WLAN Transmitters

The following charts illustrate WLAN device idle, ping storm envelope, and file transfer emission envelopes compared to the baseline (idle and file transfer) of the host laptop. An equivalent measurement noise floor is included in each chart for each band to represent the instrument noise floor, but with calibration factors applied as had been done with the emission data. These charts were used to further reduce the data to the forms that are found in Sections 2.3 and 2.5 of this report. Table A-1 has details on the organization of data charts produced from each wireless communication device tested. Every device tested in a wireless technology category was grouped together by measurement bands, so that each device may be easily compared with each other.

The legends in each chart list the data plots by host laptop computer number and WLAN device designation. For instance, Figure A1 displays emission data plots acquired from Laptop 9 with 802.11a WLAN device 11A-1 installed. Tables 2.2-5 to 2.2-7 list the WLAN device designations and associated manufacturers. Table 2.2-4 provides the host laptop designations and manufacturers.

Table A-1: Organization of Charts in this Section

Wireless Technology	Band 1 Figure	Band 2 Figure	Band 3 Figure	Band 4 Figure	Band 5 Figure
802.11A	A1	A2	A3	A4	A5
802.11B	A6-A9	A10-A13	A14-A17	A18-A21	A22-A25
Bluetooth	A26-A29	A30-A33	A34-A37	A38-A41	A44-A45

A.1 802.11a WLAN Devices

A.1.1 Band 1b

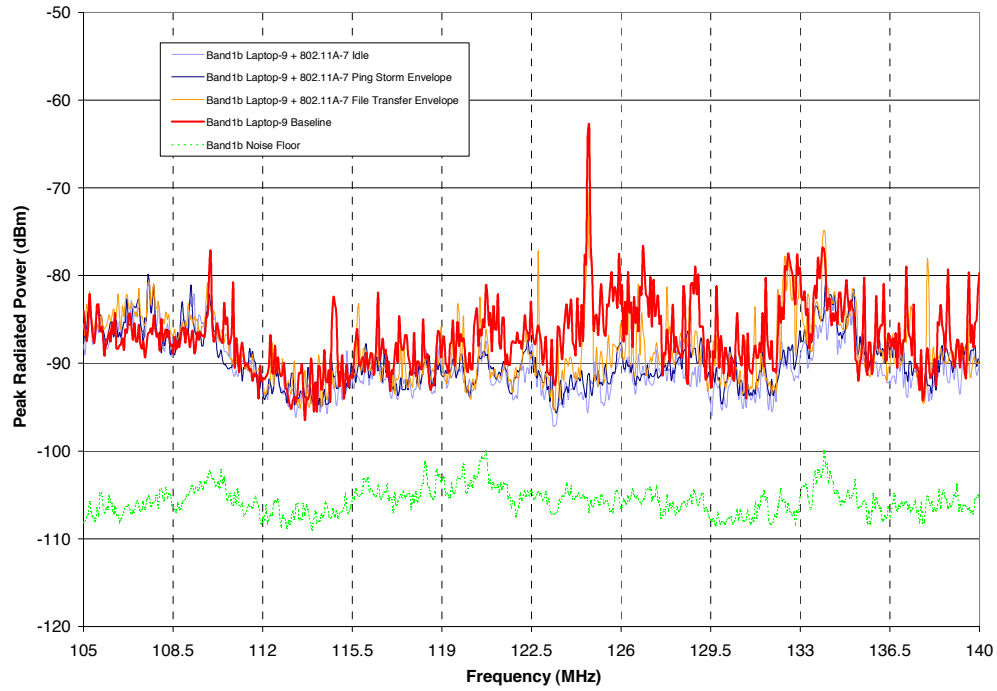


Figure A1: Laptop 9 and 802.11A-7, Band 1b.

A.1.2 Band 2

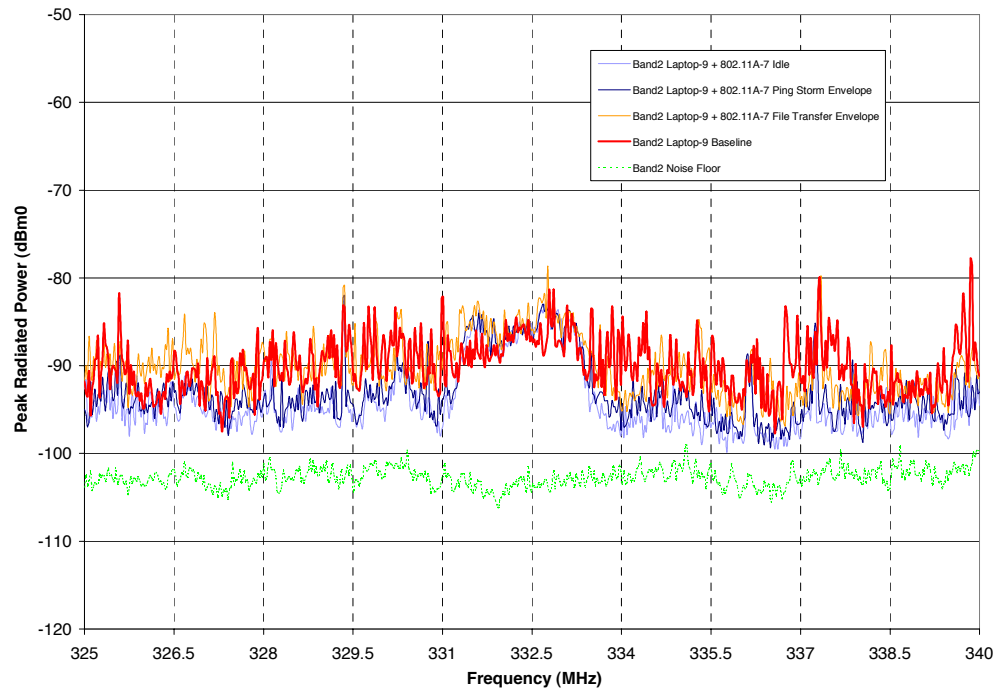


Figure A2: Laptop 9 and 802.11A-7, Band 2.

A.1.3 Band 3

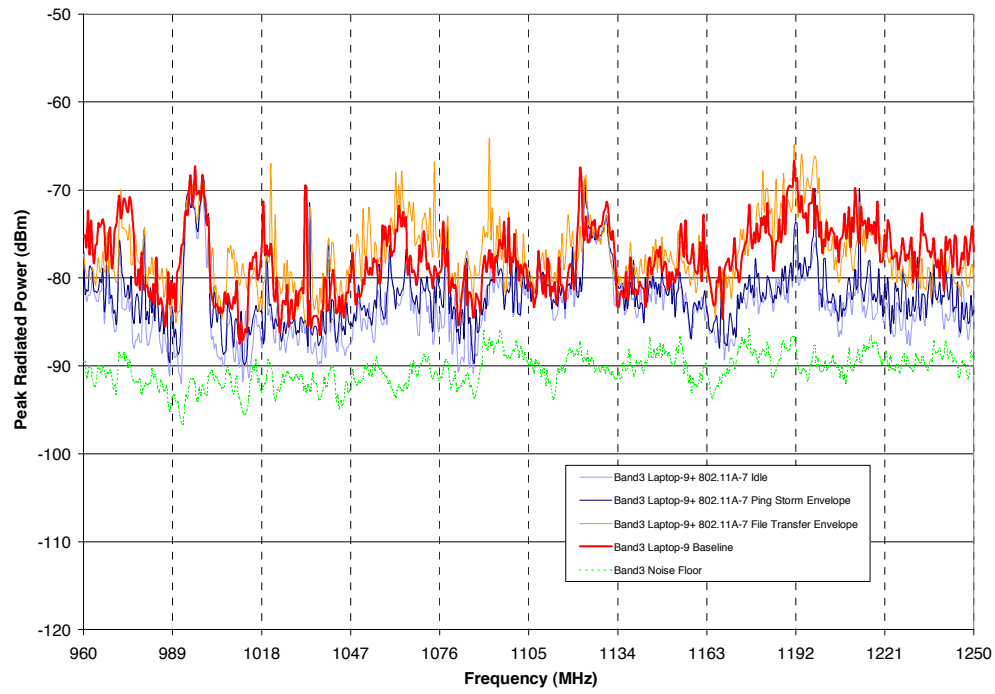


Figure A3: Laptop 9 and 802.11A-7, Band 3.

A.1.4 Band 4

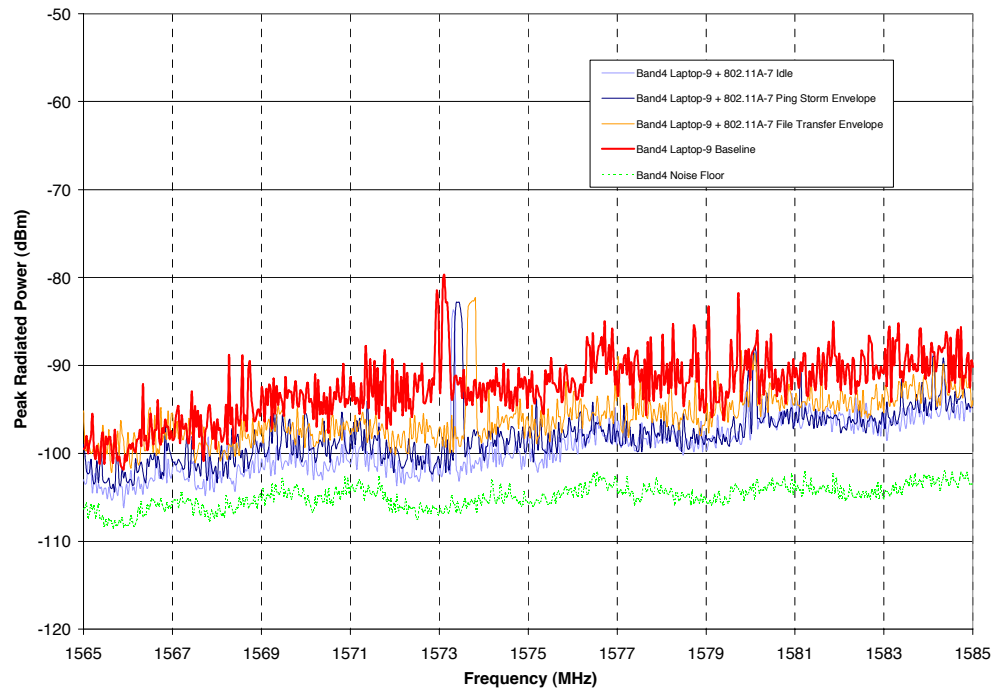


Figure A4: Laptop 9 and 802.11A-7, Band 4.

A.1.5 Band 5

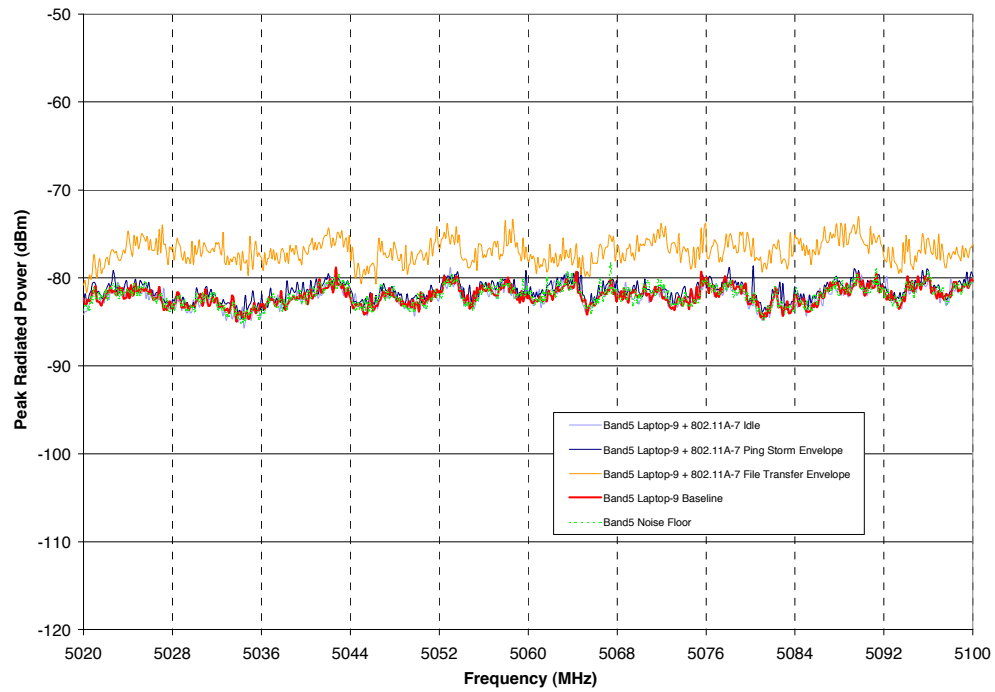


Figure A5: Laptop 9 and 802.11A, Band5.

A.2 802.11b WLAN Devices

A.2.1 Band 1b

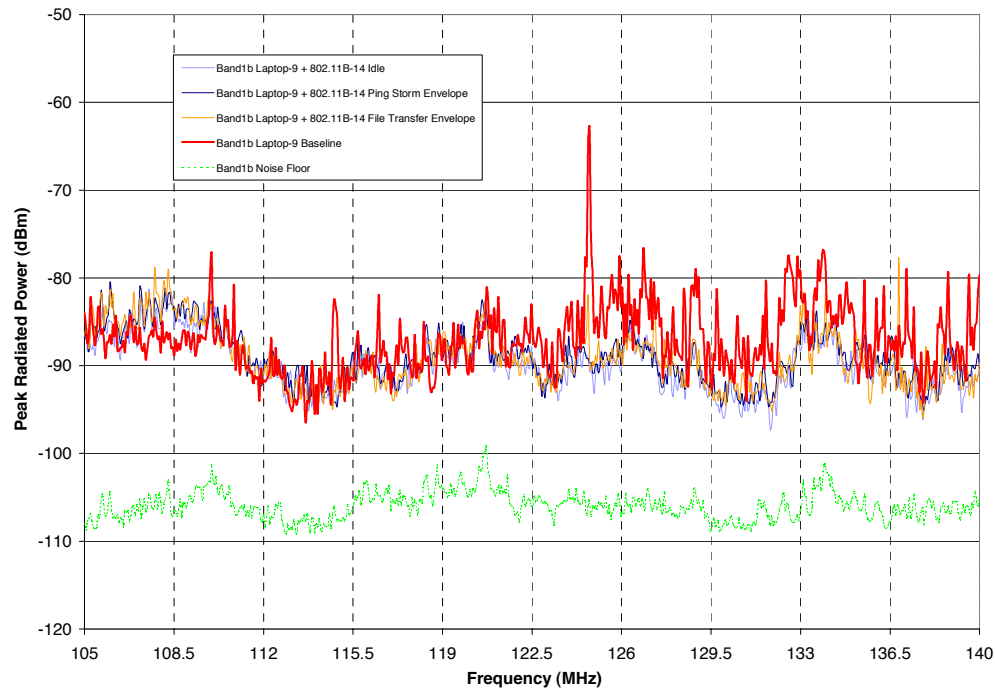


Figure A6: Laptop 9 and 802.11B, Band 1b.

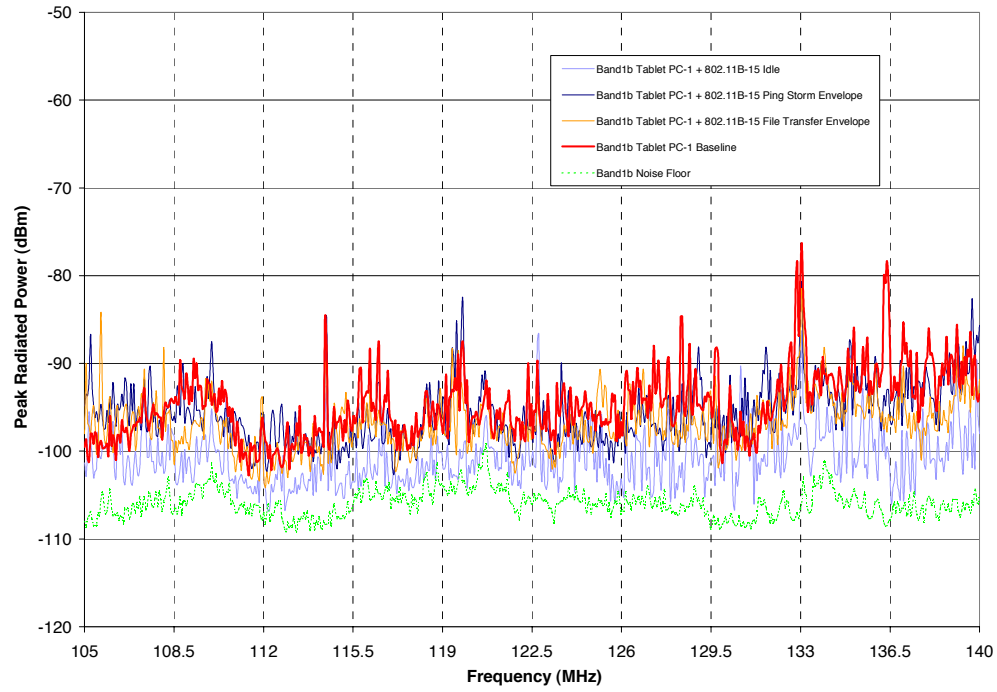


Figure A7: Tablet PC 1 and 802.11B-15, Band 1b.

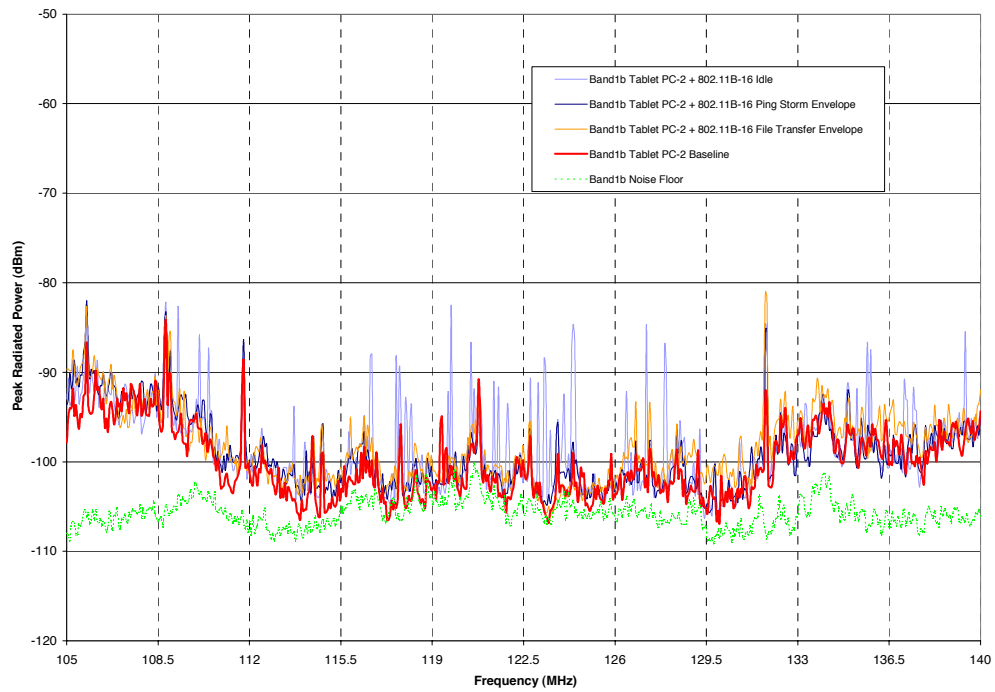


Figure A8: Tablet PC 2 and 802.11B-16, Band 1b.

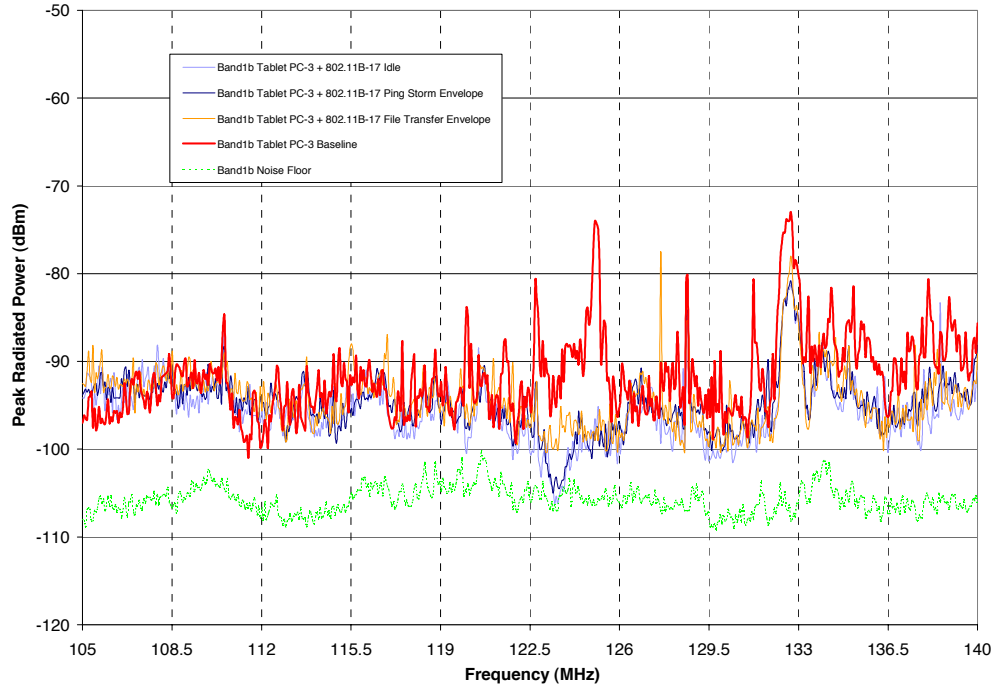


Figure A9: Tablet PC 3 and 802.11B-17, Band 1b.

A.2.2 Band 2

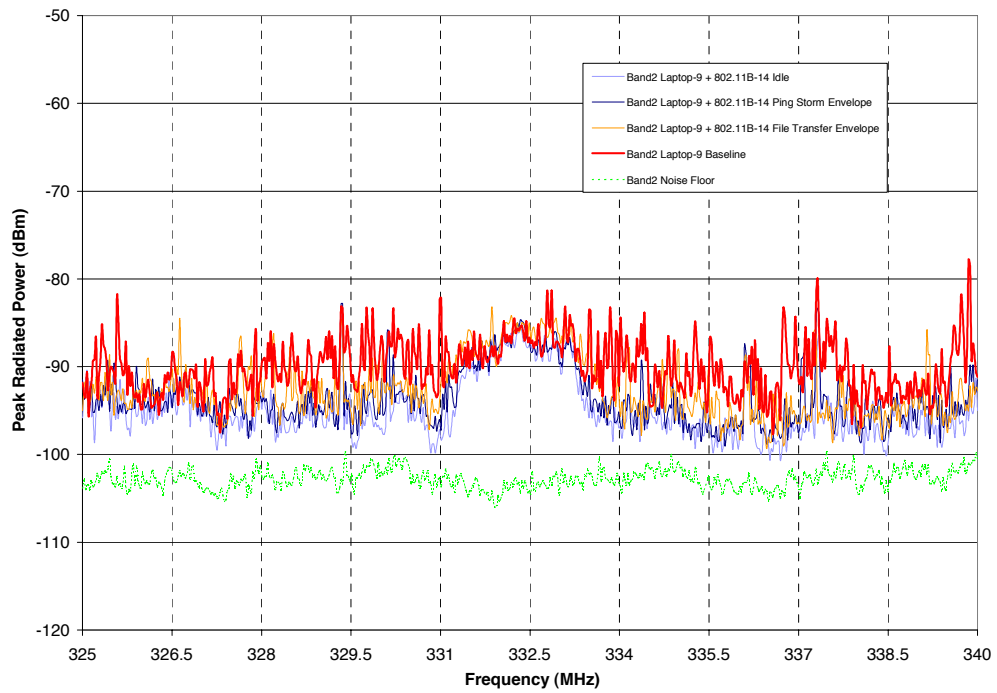


Figure A10: Laptop 9 and 802.11B-14, Band 2.

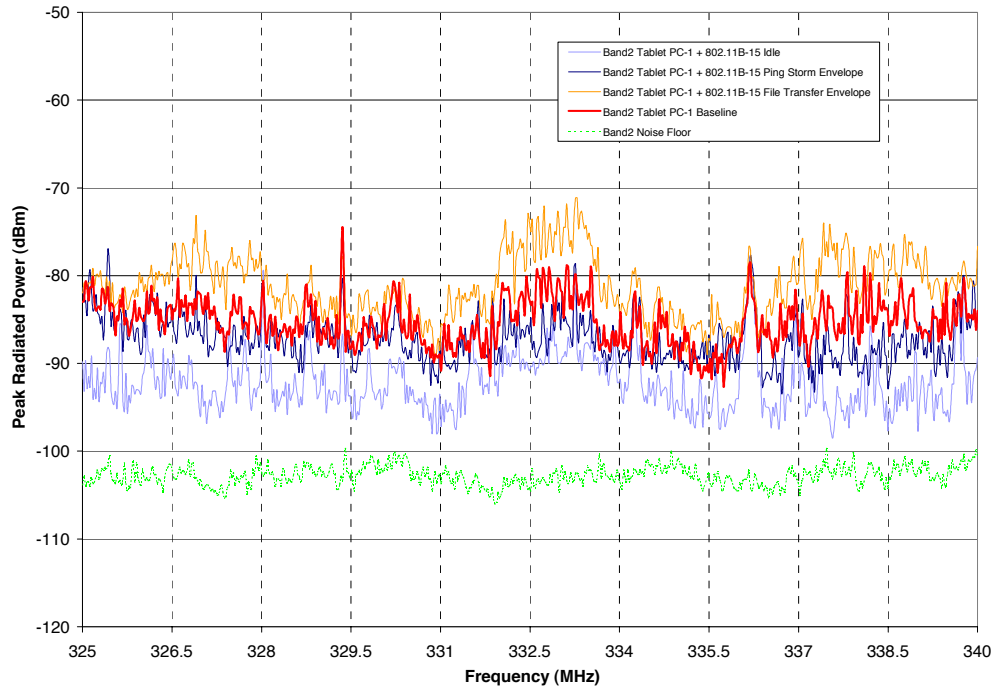


Figure A11: Tablet PC 1 and 802.11B-15, Band 2.

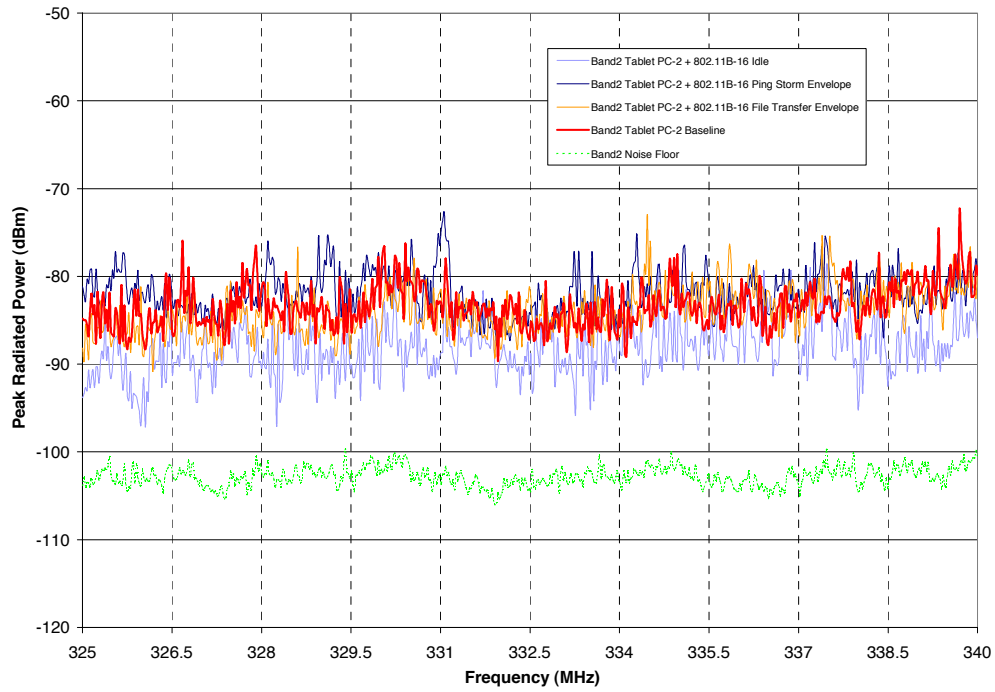


Figure A12: Tablet PC 2 and 802.11B-16, Band 2.

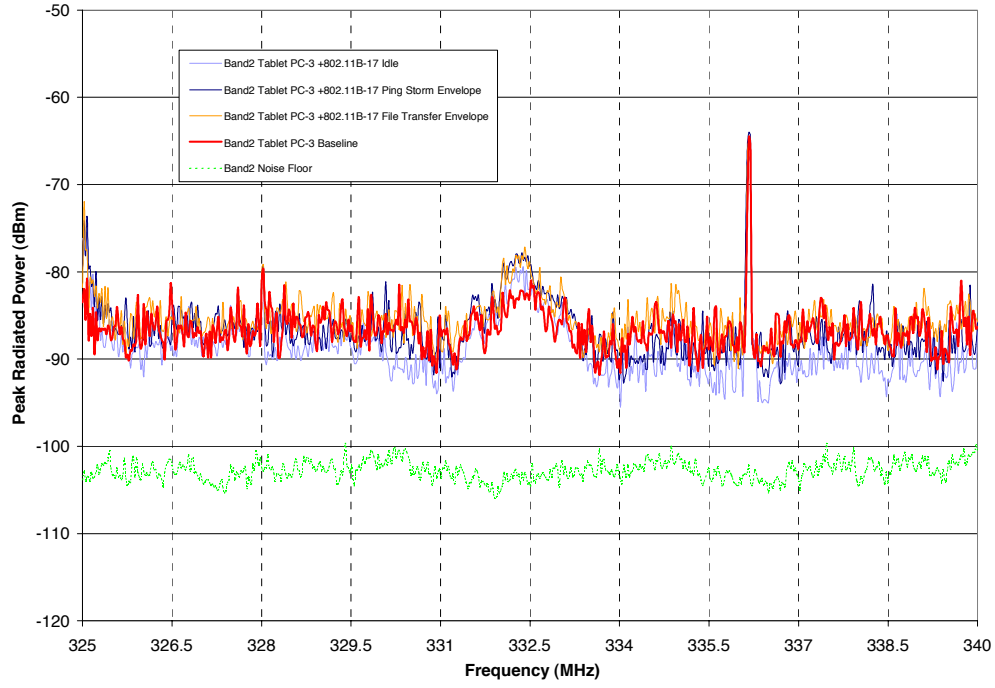


Figure A13: Tablet PC 3 and 802.11B-17, Band 2.

A.2.3 Band 3

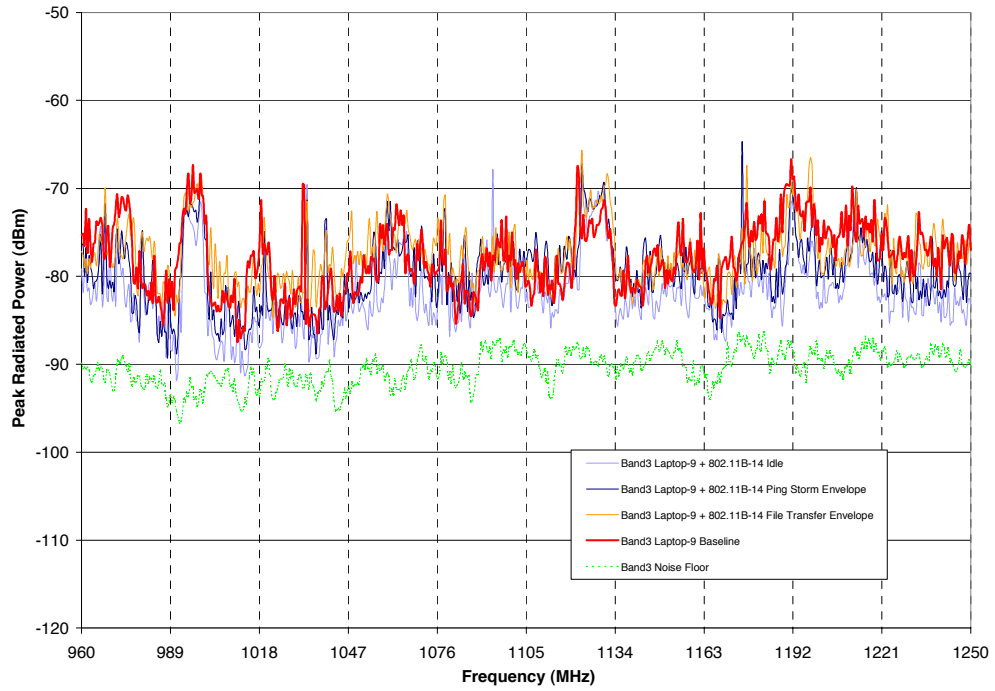


Figure A14: Laptop 9 and 802.11B-14, Band 3.

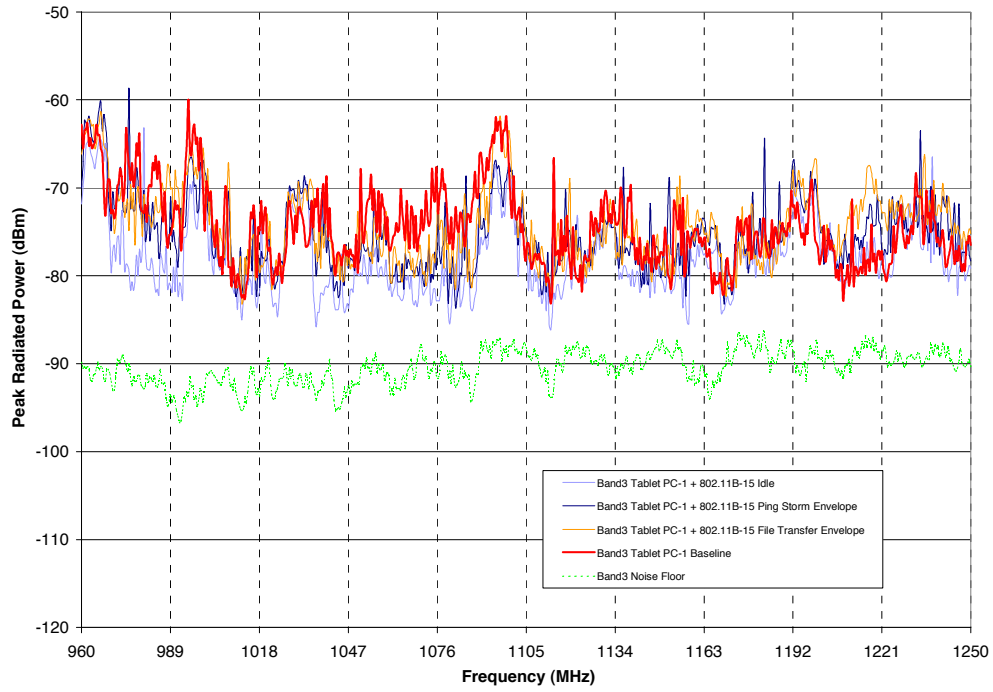


Figure A15: Tablet PC 1 and 802.11B-15, Band 3.

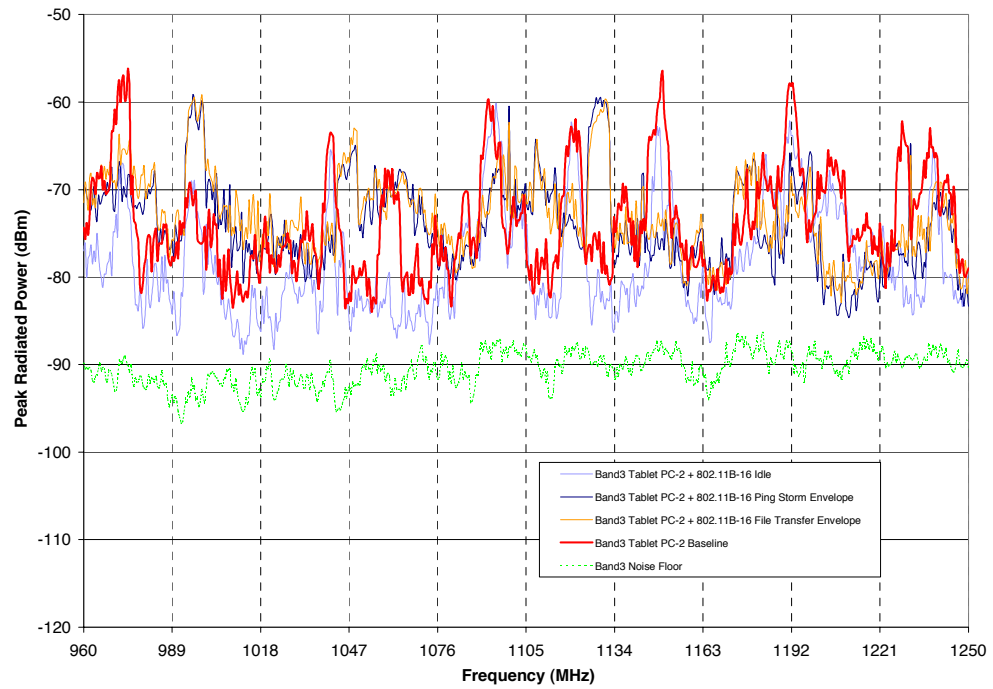


Figure A16: Tablet PC 2 and 802.11B-16, Band 3.

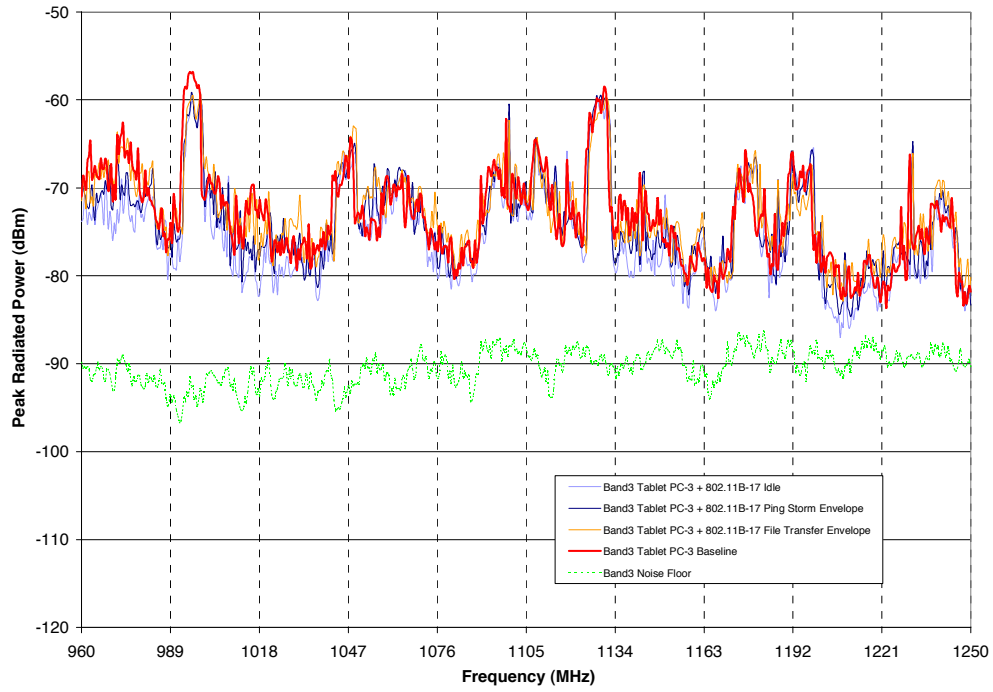


Figure A17: Tablet PC 3 and 802.11B-17, Band 3.

A.2.4 Band 4

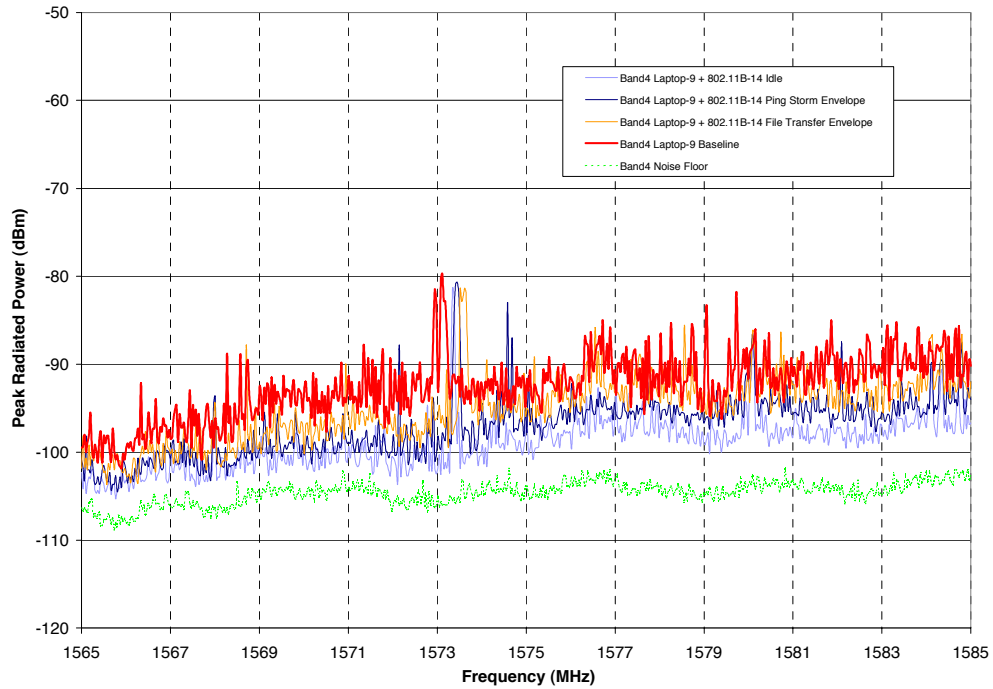


Figure A18: Laptop 9 and 802.11B-14, Band 4.

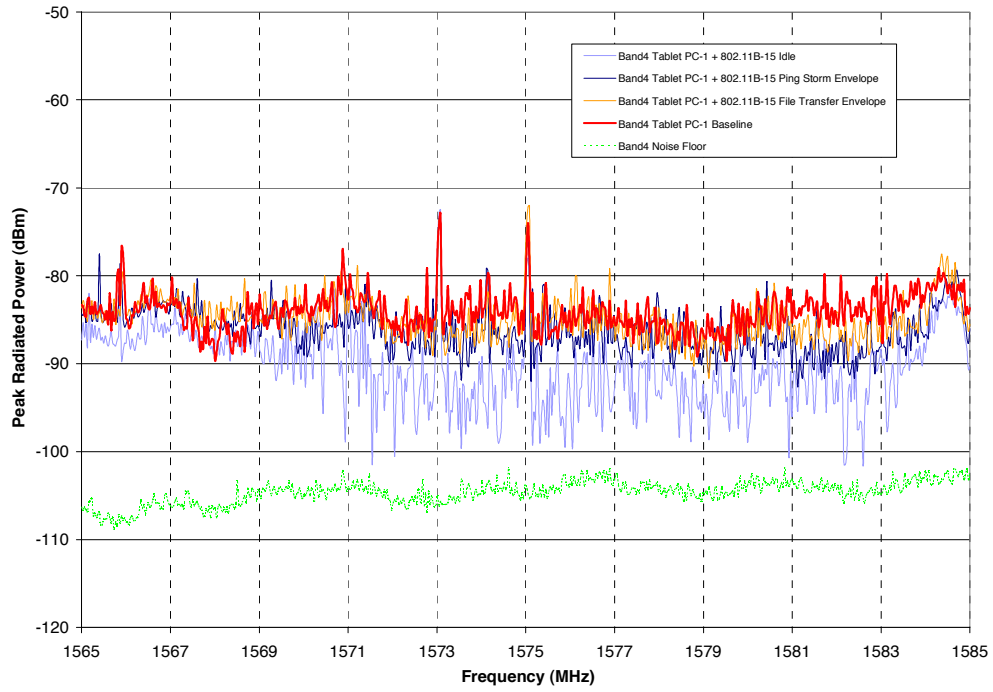


Figure A19: Tablet PC 1 and 802.11B-15, Band 4.

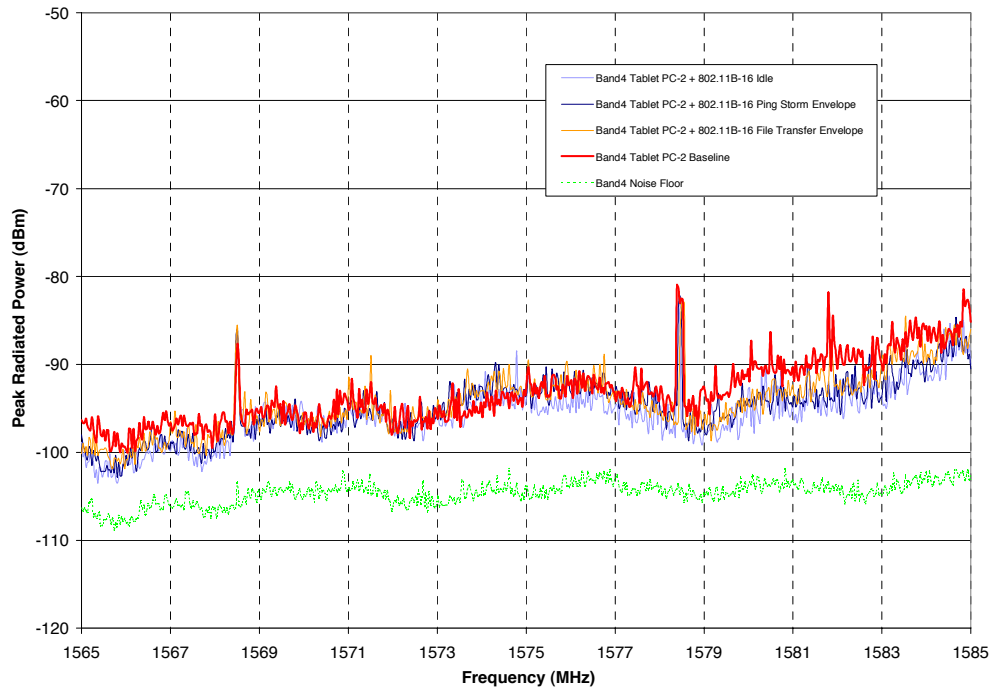


Figure A20: Tablet PC 2 and 802.11B-16, Band 4.

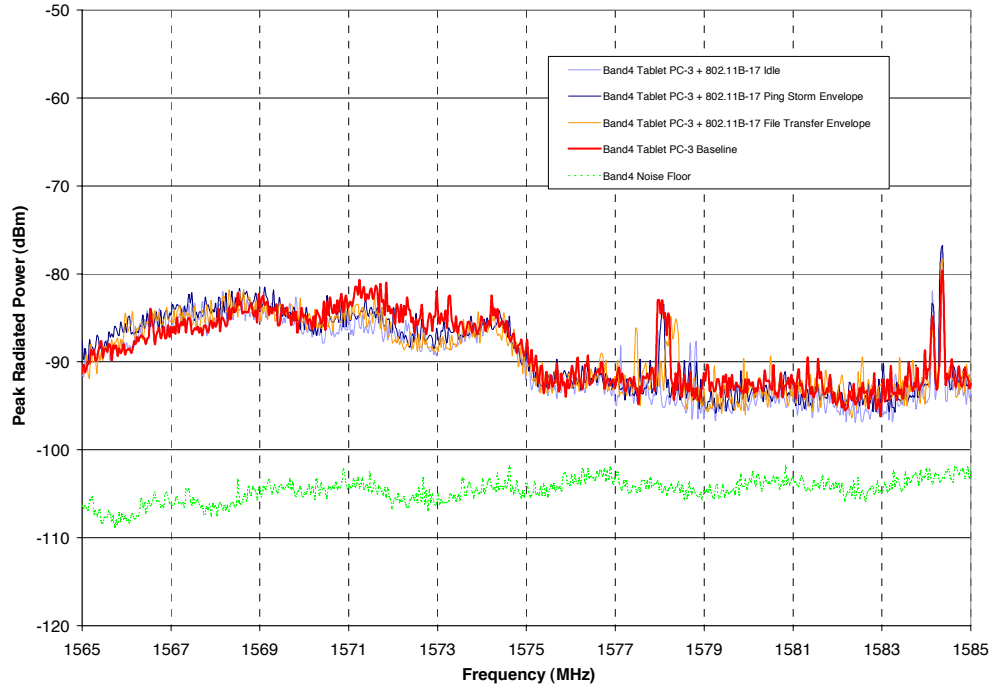


Figure A21: Tablet PC 3 and 802.11B-17, Band 4.

A.2.5 Band 5

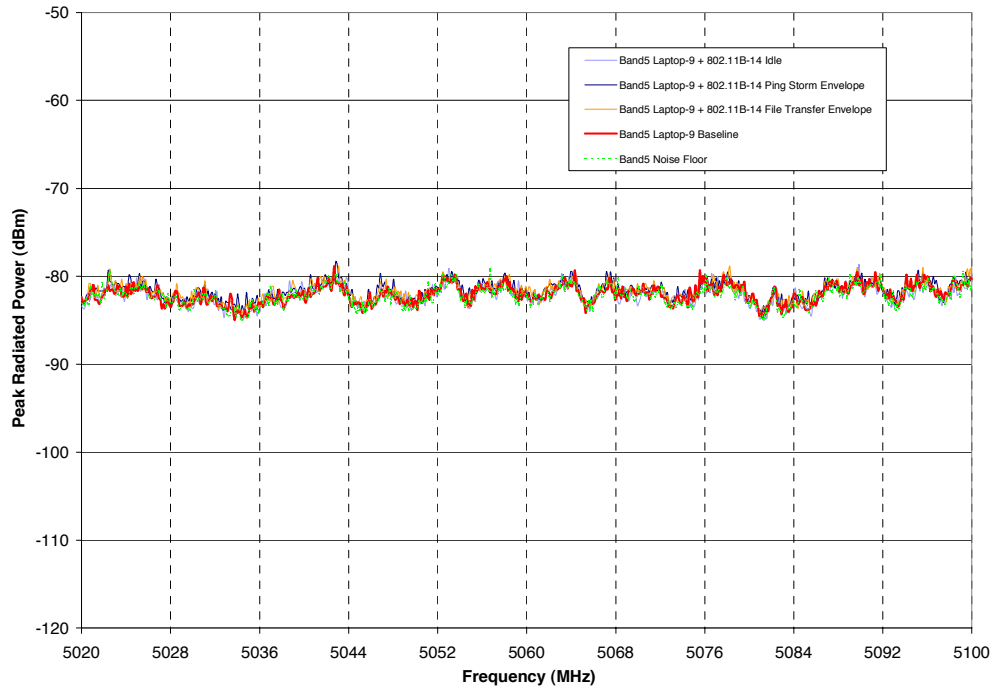


Figure A22: Laptop 9 and 802.11B-14, Band 5.

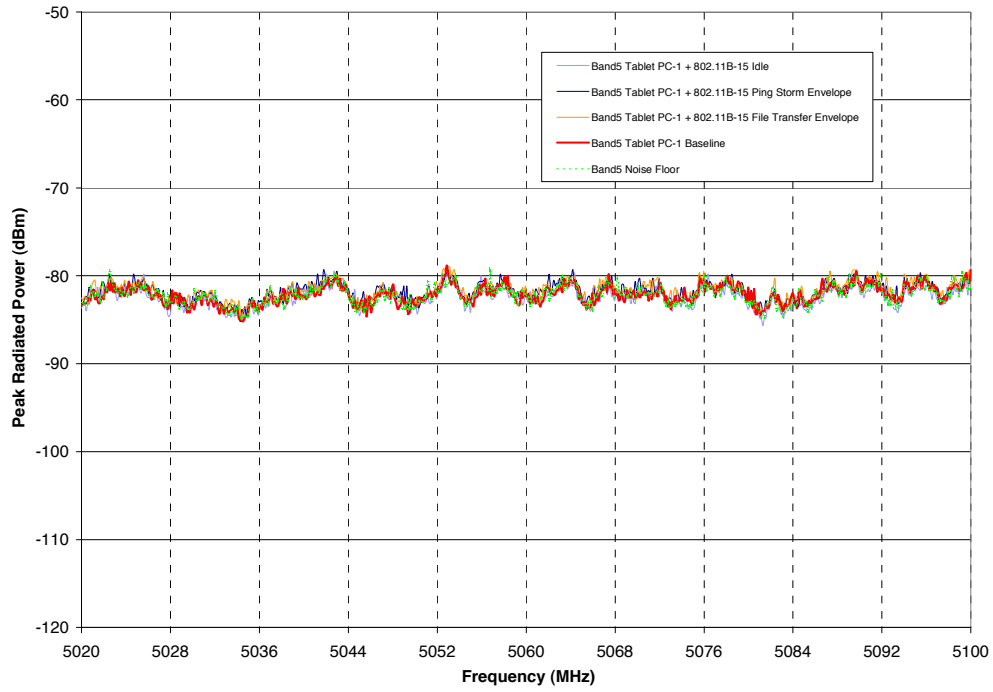


Figure A23: Tablet PC 1 and 802.11B-15, Band 5.

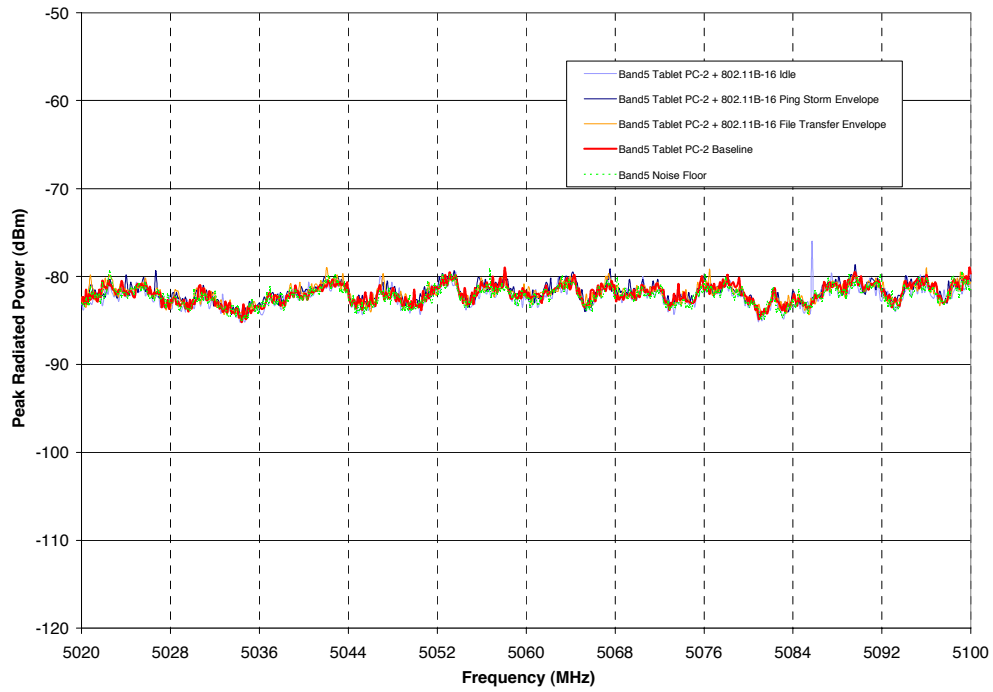


Figure A24: Tablet PC 2 and 802.11B-16, Band 5.

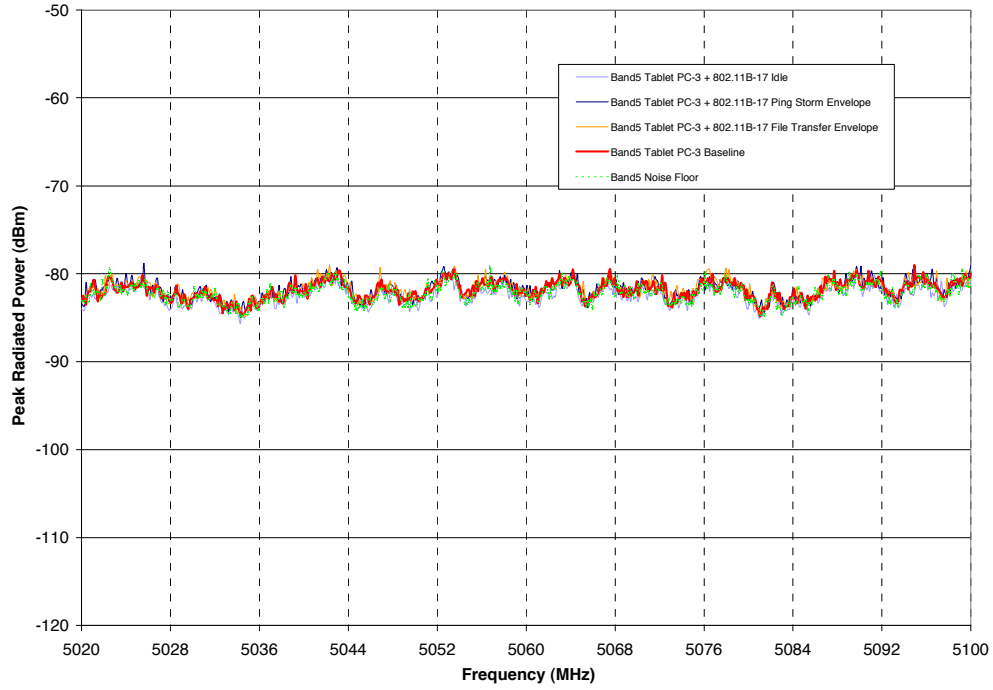


Figure A25: Tablet PC 3 and 802.11B-17, Band 5.

A.3 Bluetooth Devices

A.3.1 Band 1b

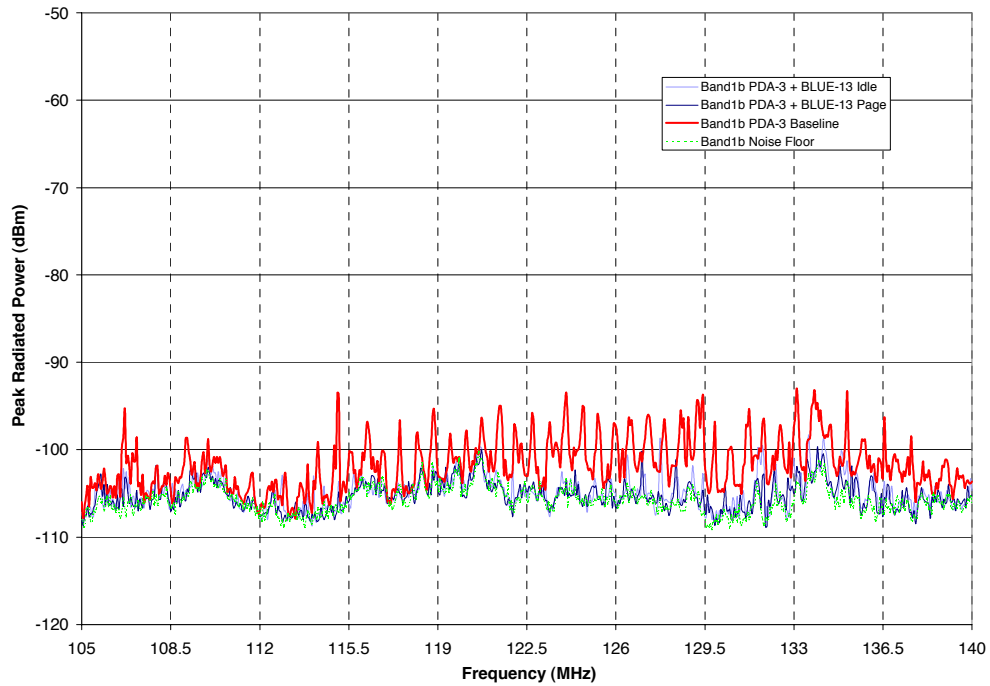


Figure A26: PDA 3 and BLUE-13, Band 1b.

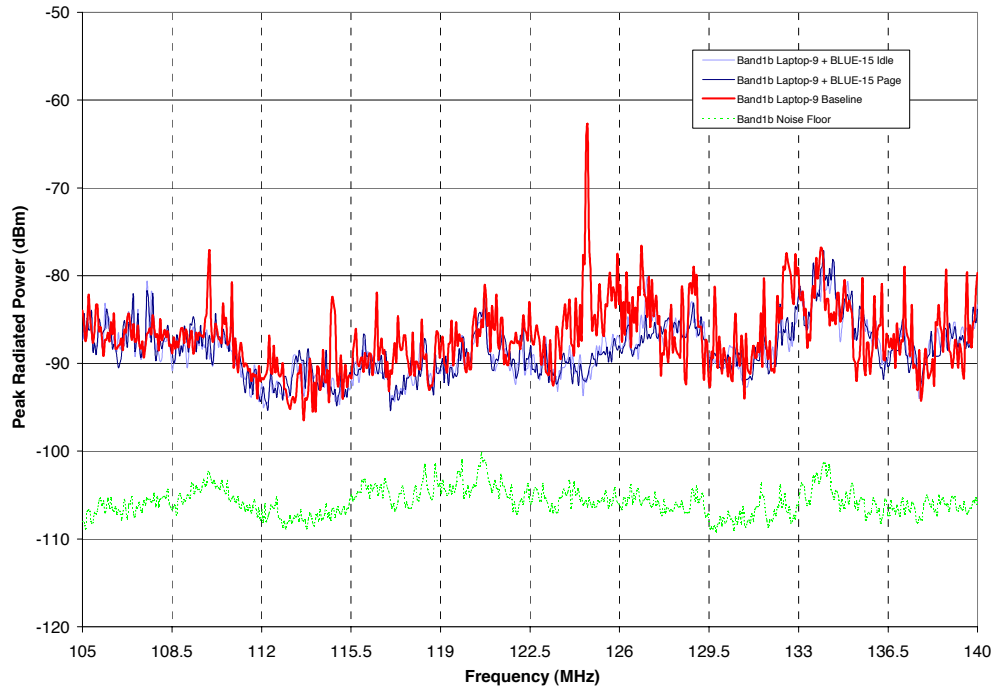


Figure A27: Laptop 9 and BLUE-15, Band 1b.

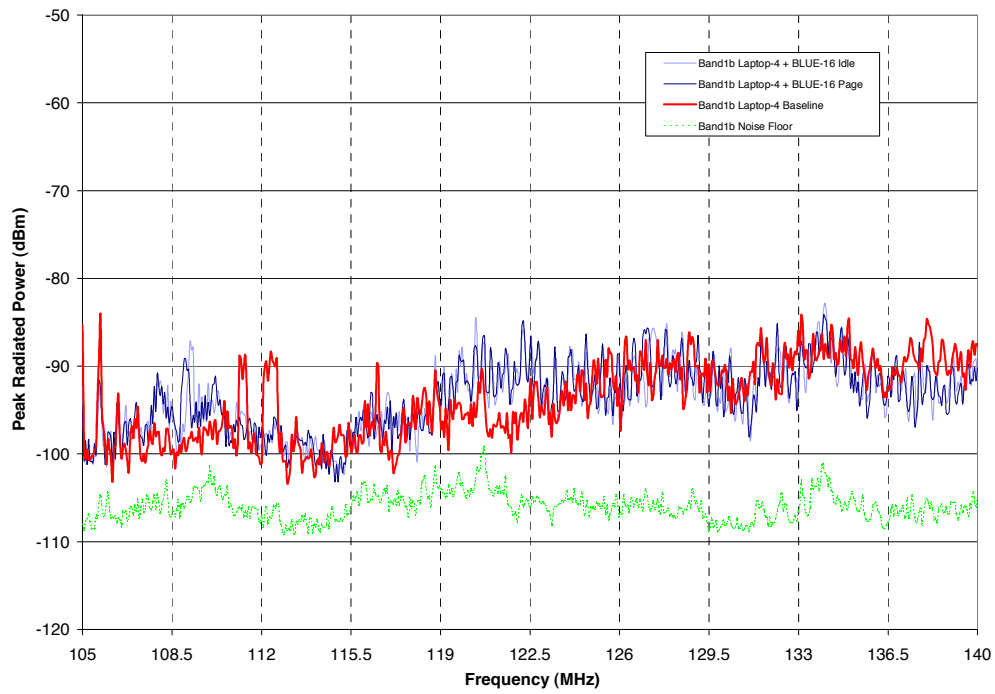


Figure A28: Laptop 4 and BLUE-16, Band 1b.

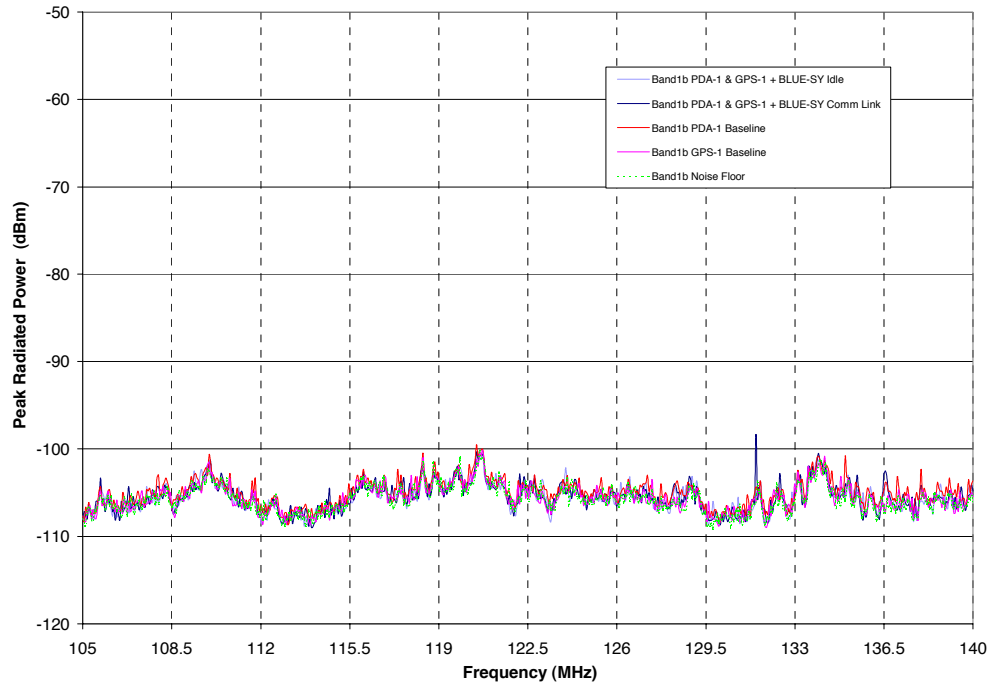


Figure A29: PDA 1, GPS 1 and BLUE-SY, Band 1b.

A.3.2 Band 2

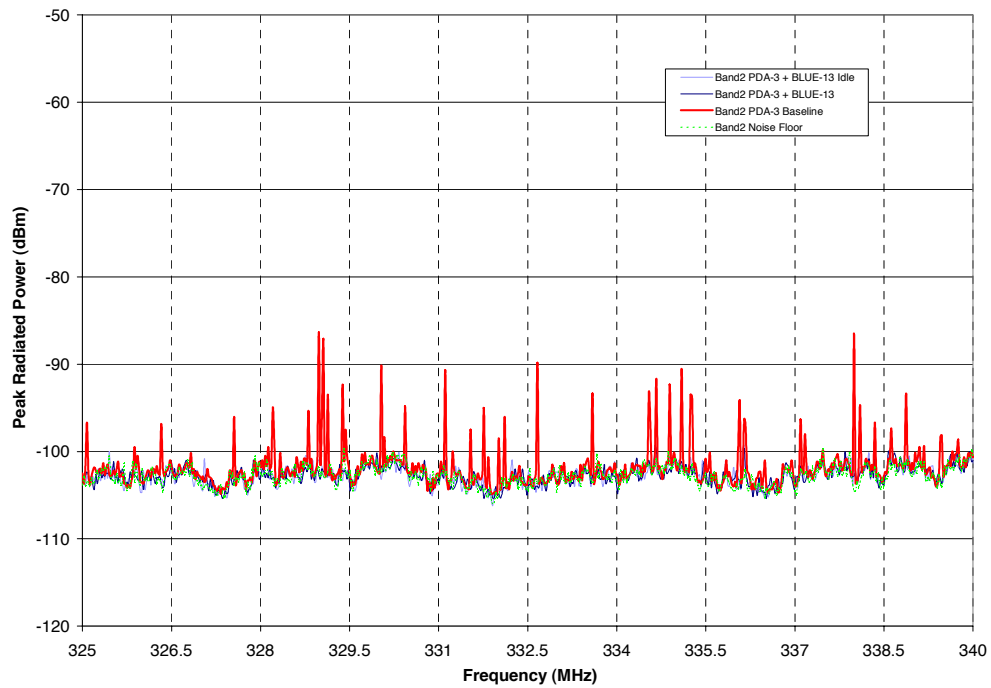


Figure A30: PDA 3 and BLUE-13, Band 2.

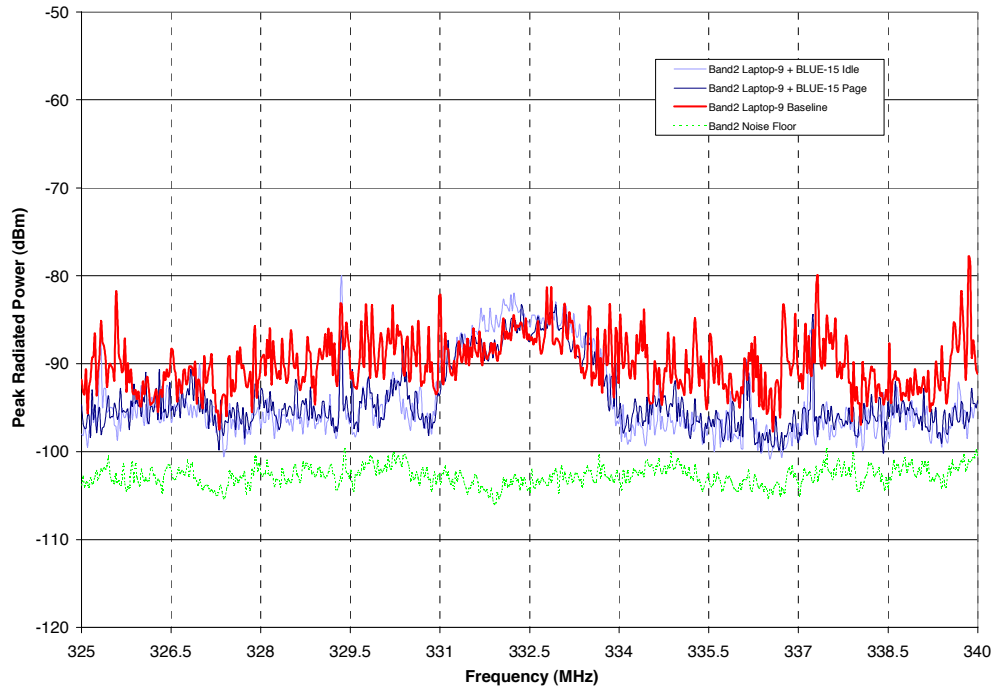


Figure A31: Laptop 9 and BLUE-15, Band 2.

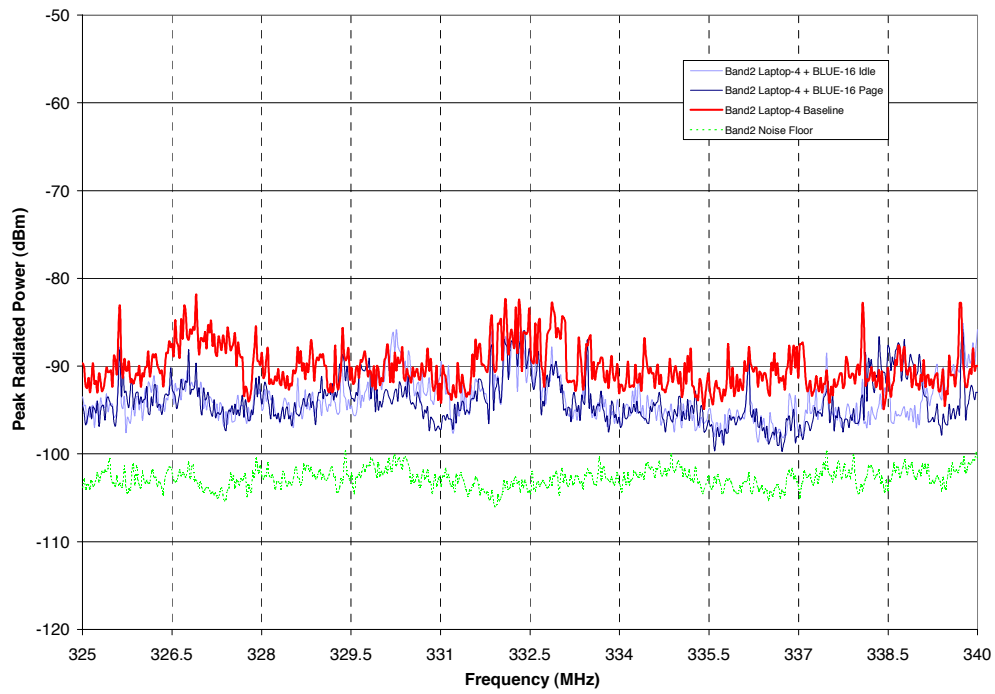


Figure A32: Laptop 4 and BLUE-16, Band 2.

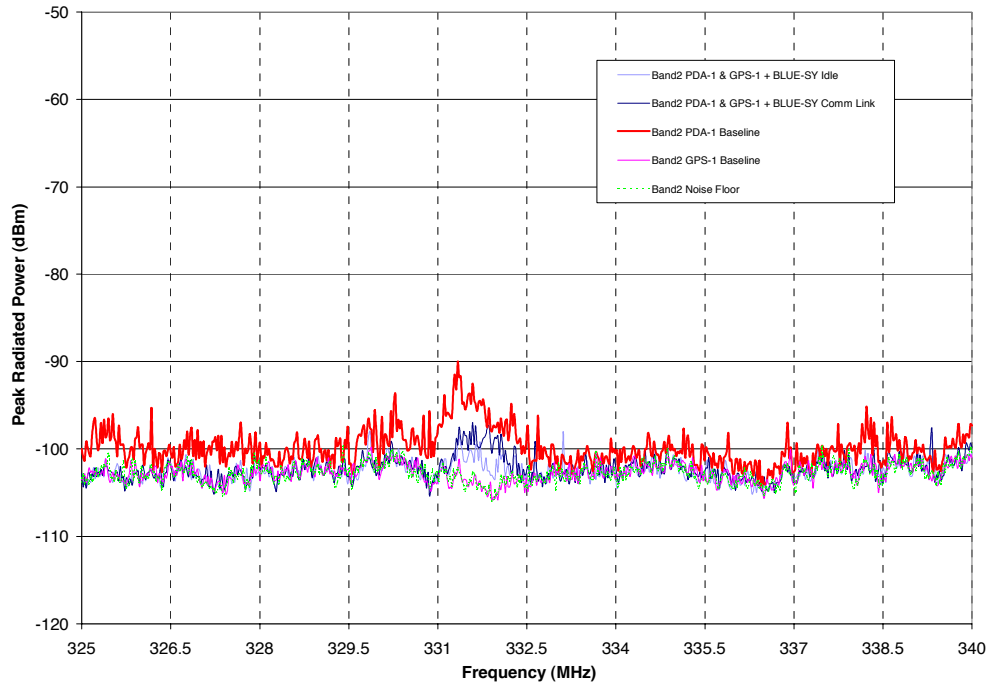


Figure A33: PDA 1, GPS 1 and BLUE-SY, Band 2.

A.3.3 Band 3

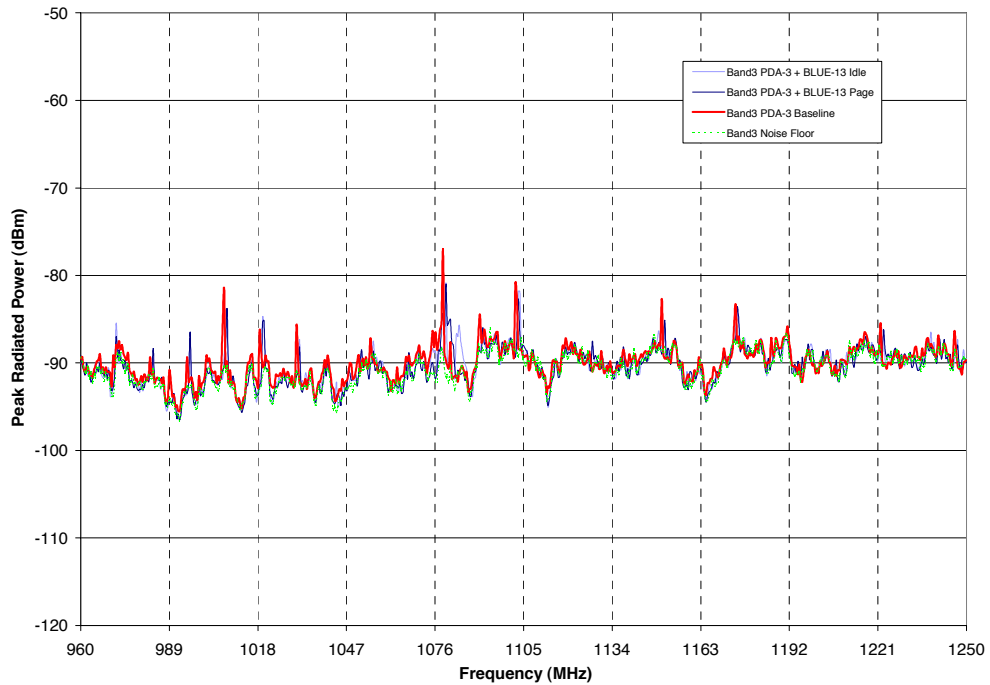


Figure A34: PDA 3 and BLUE-13, Band 3.

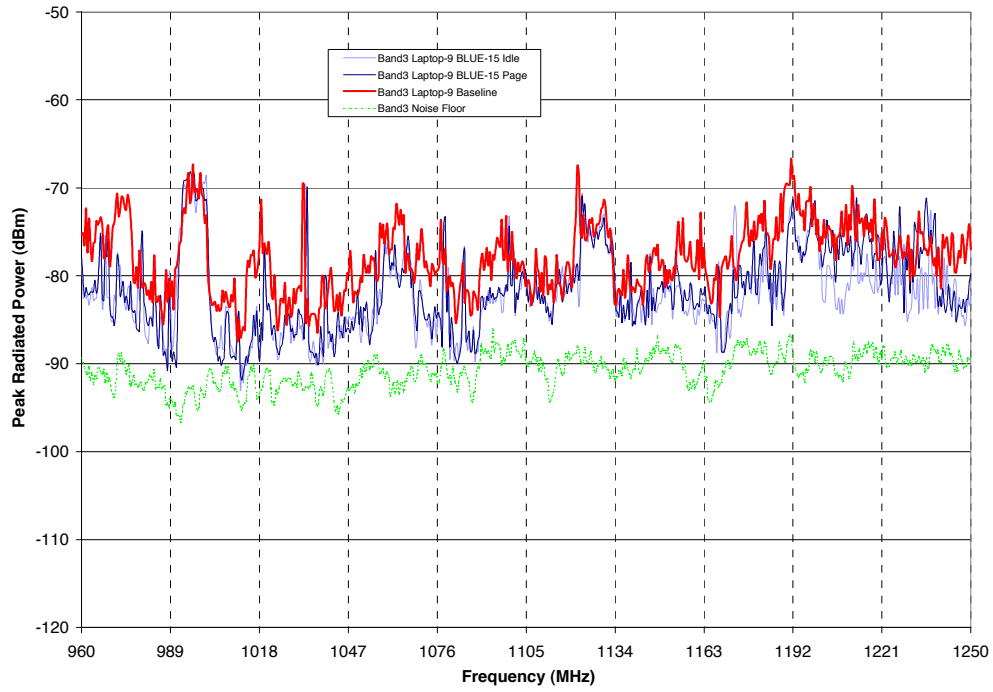


Figure A35: Laptop 9 and BLUE-15, Band 3.

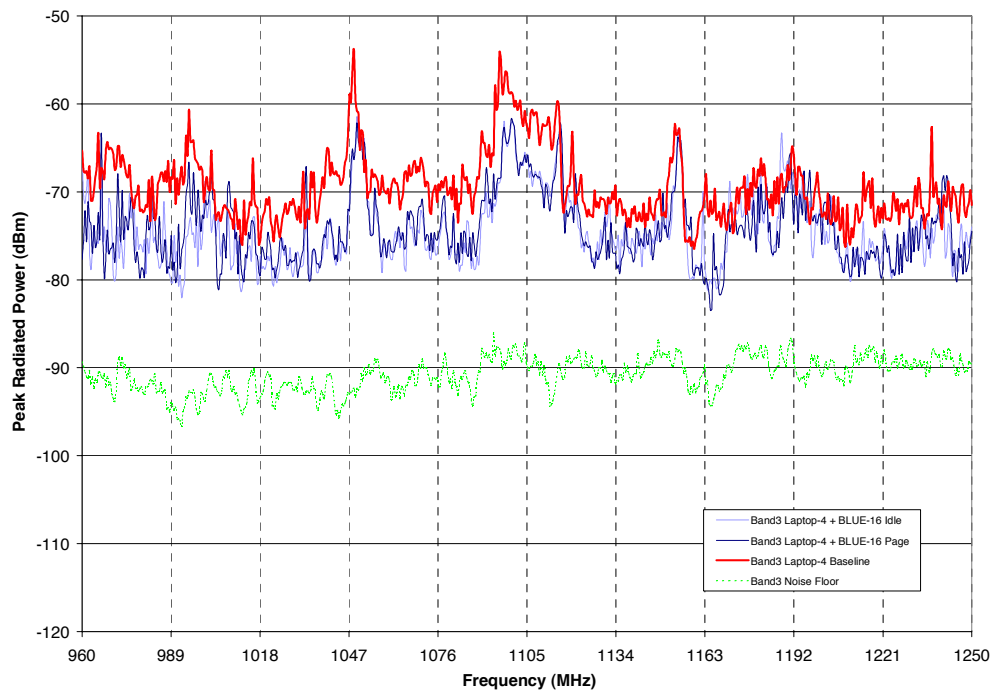


Figure A36: Laptop 4 and BLUE-16, Band 3.

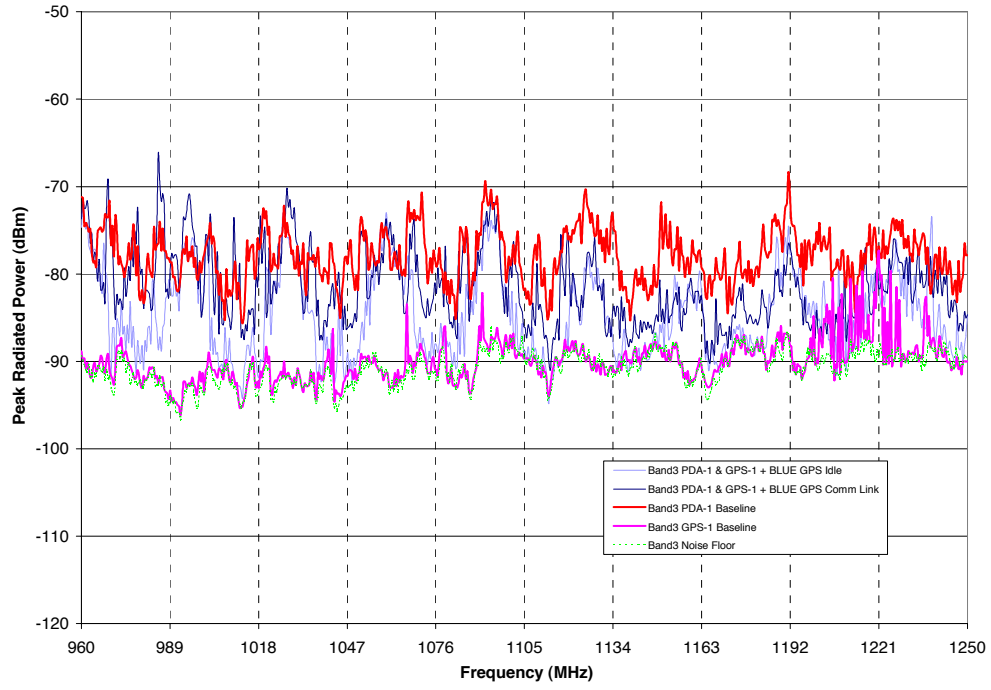


Figure A37: PDA 1, GPS 1 and BLUE-SY, Band 3.

A.3.4 Band 4

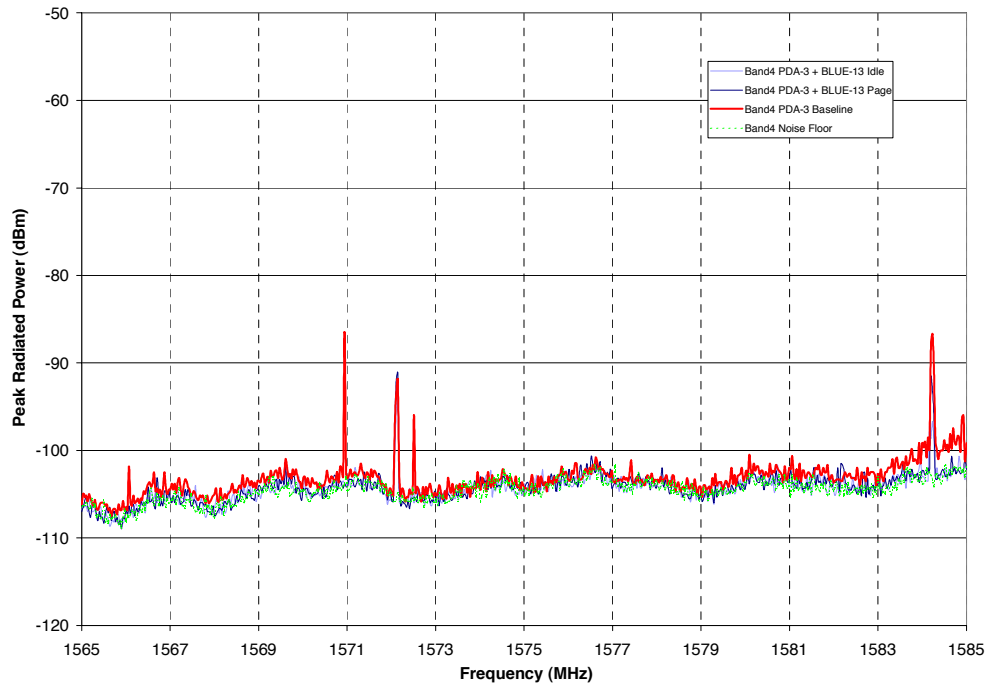


Figure A38: PDA 3 and BLUE-13, Band 4.

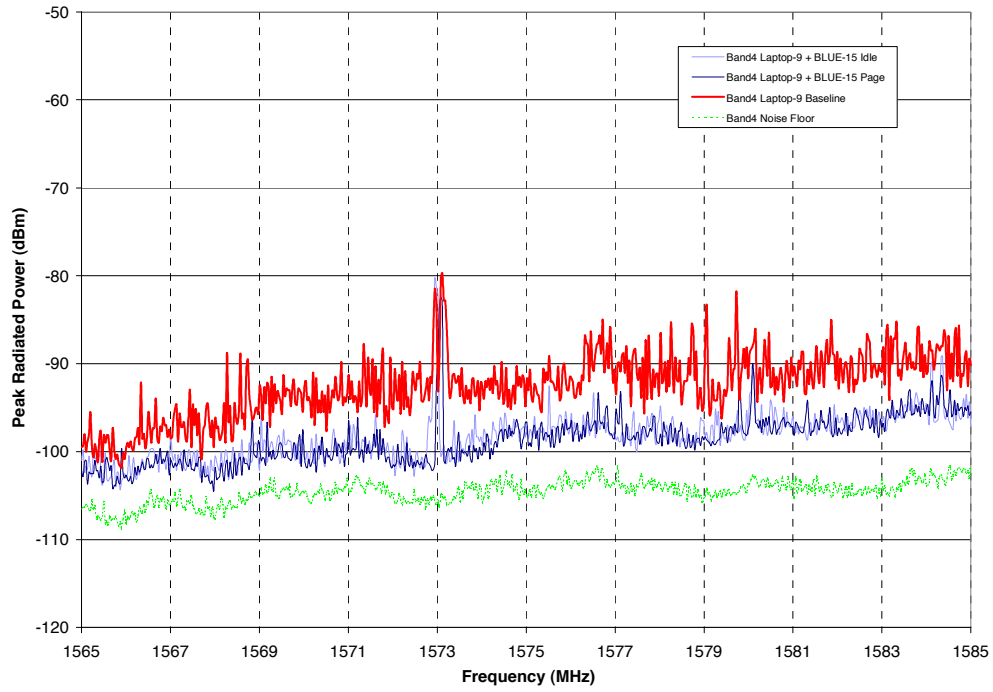


Figure A39: Laptop 9 and BLUE-15, Band 4.

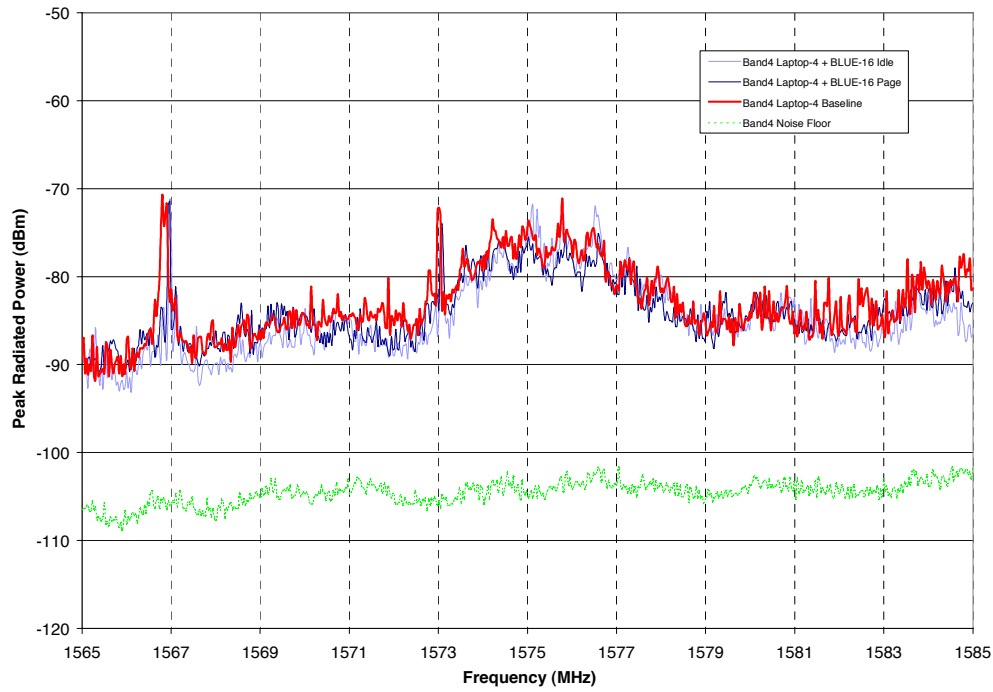


Figure A40: Laptop 4 and BLUE-16, Band 4.

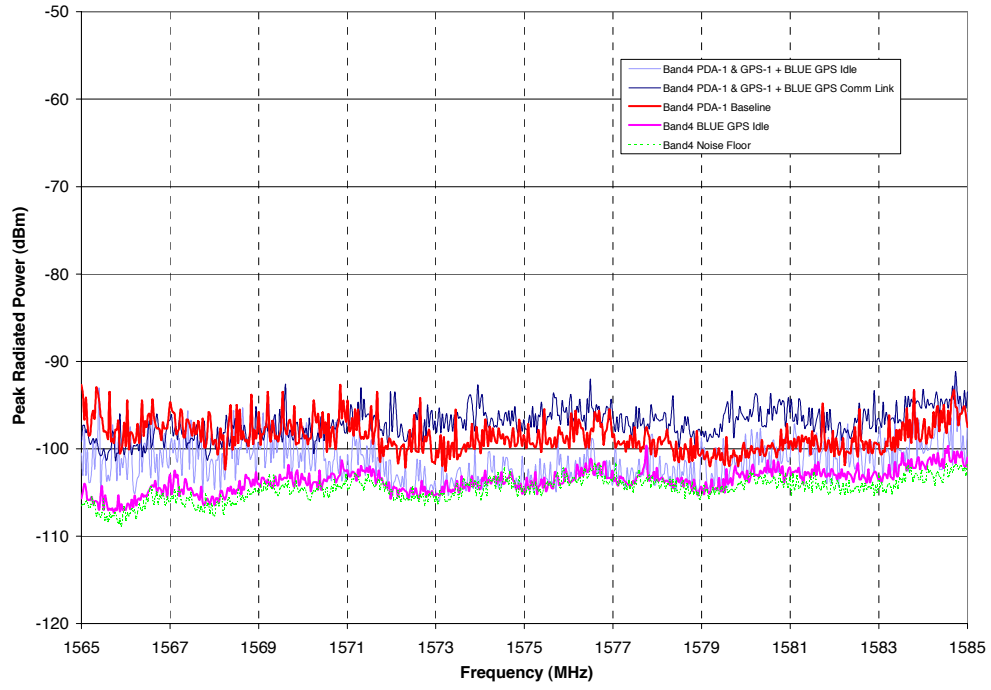


Figure A41: PDA 1, GPS 1 and BLUE-SY, Band 4.

A.3.5 Band 5

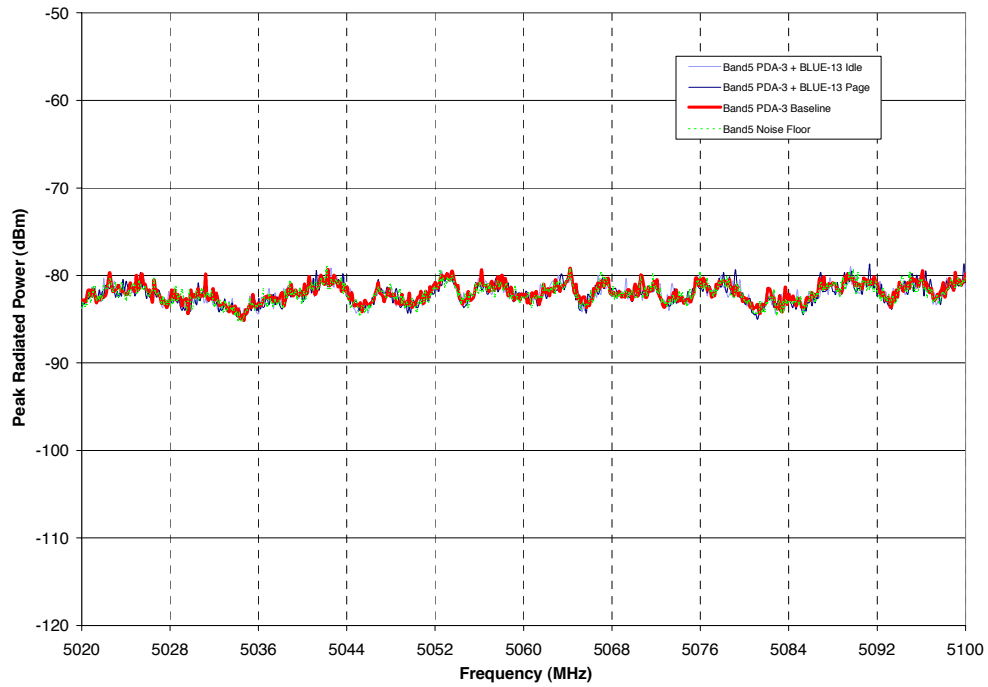


Figure A42: PDA 3 and BLUE-13, Band 5.

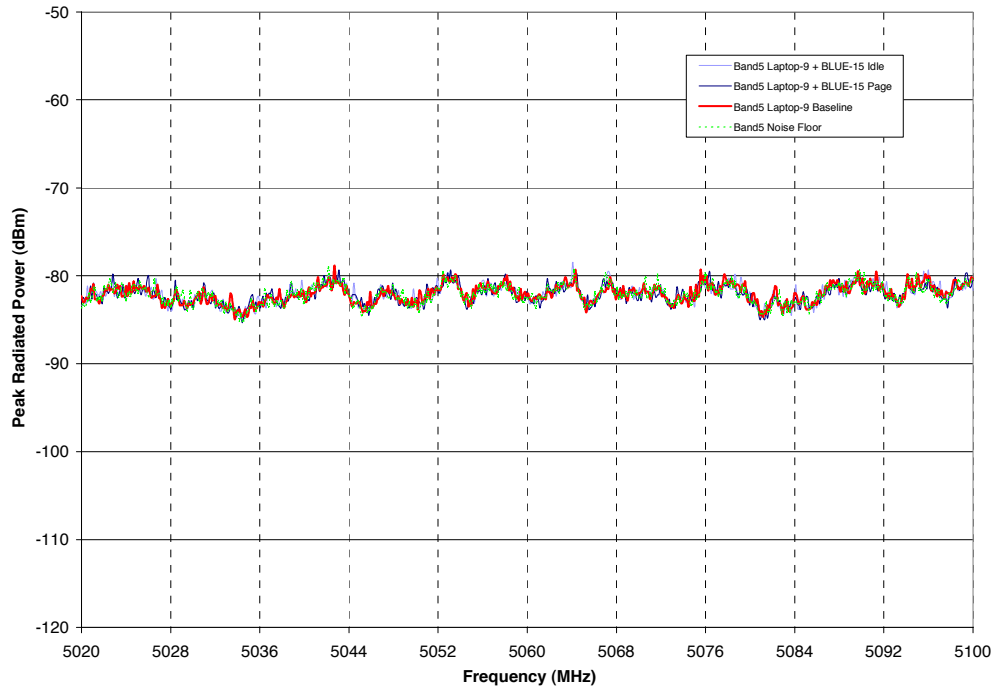


Figure A43: Laptop 9 and BLUE-15, Band 5.

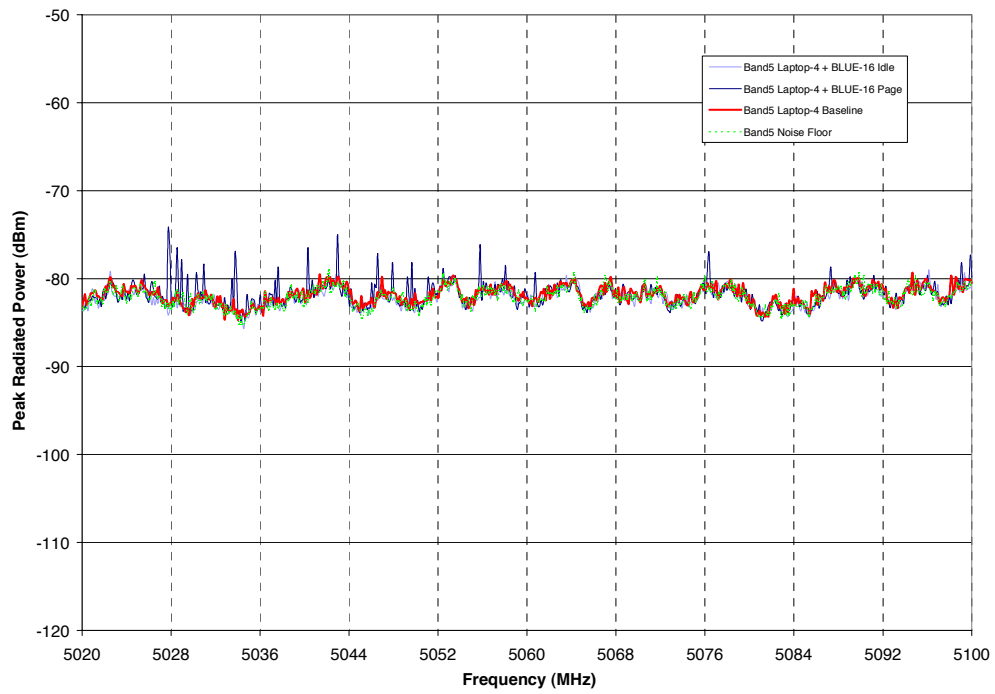


Figure A44: Laptop 4 and BLUE-16, Band 5.

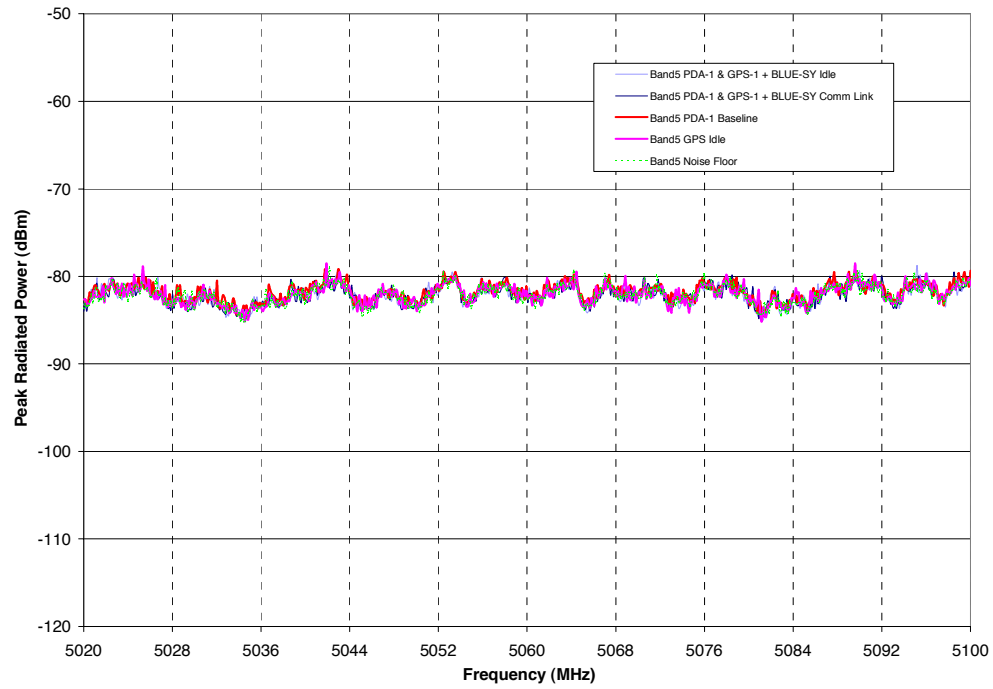


Figure A45: PDA 1, GPS 1 and BLUE-SY, Band 5.

Appendix B: Graphical Measurement Results of Non-Intentional Transmitters Including Computer Laptops and Personal-Digital-Assistants

The following charts show the results of individual modes tested for each non-intentional transmitter. These charts were reduced further to achieve the maximum radiated emissions envelope for each host device, as discussed and seen in section 2.4. Once again, the equivalent noise floor was added to the charts to show the emissions from the devices were above the calibrated noise floor from the measuring instrument. The organization is such that each host device is grouped together according to the measurement frequency band.

B.1 Band 1b

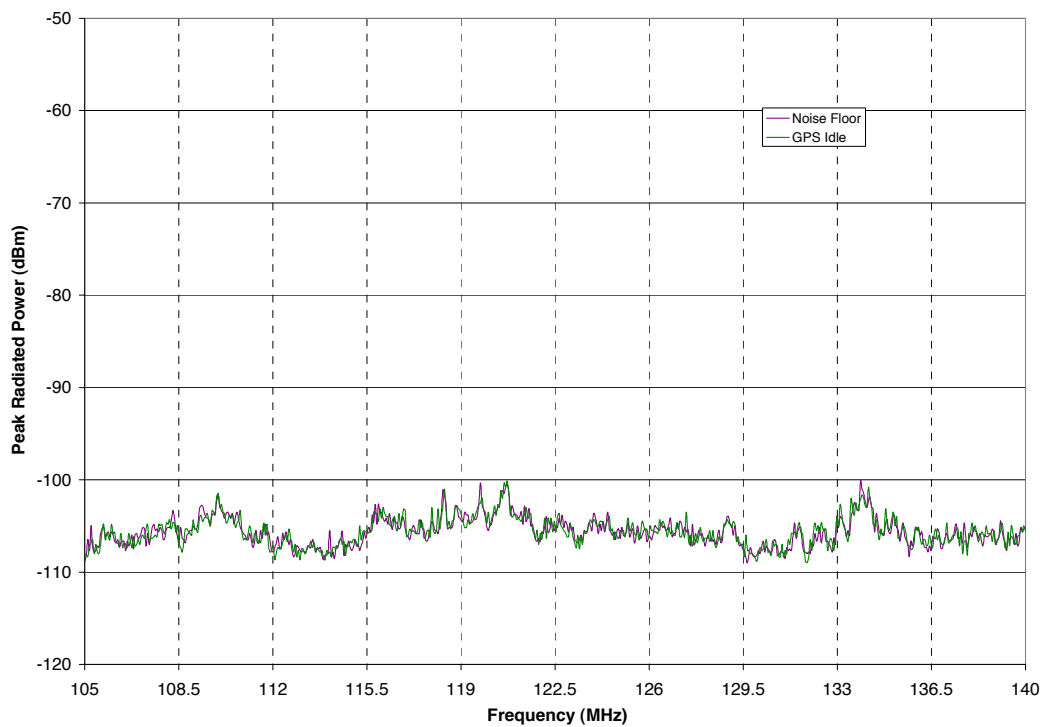


Figure B1: GPS 1, Band 1b.

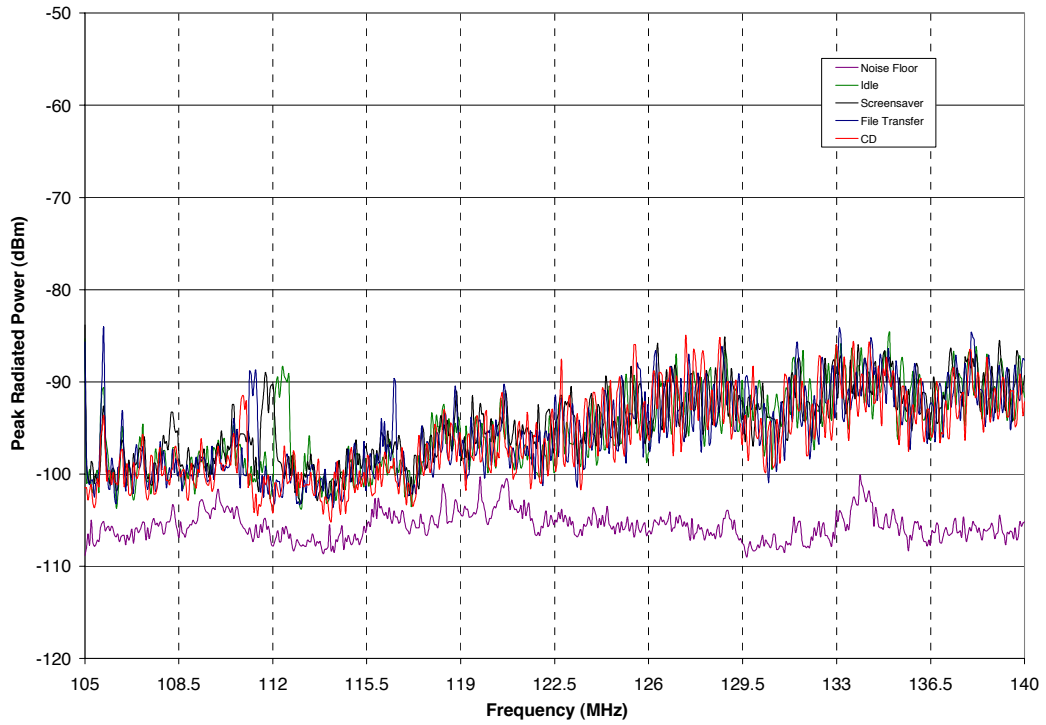


Figure B2: Laptop 4, Band 1b.

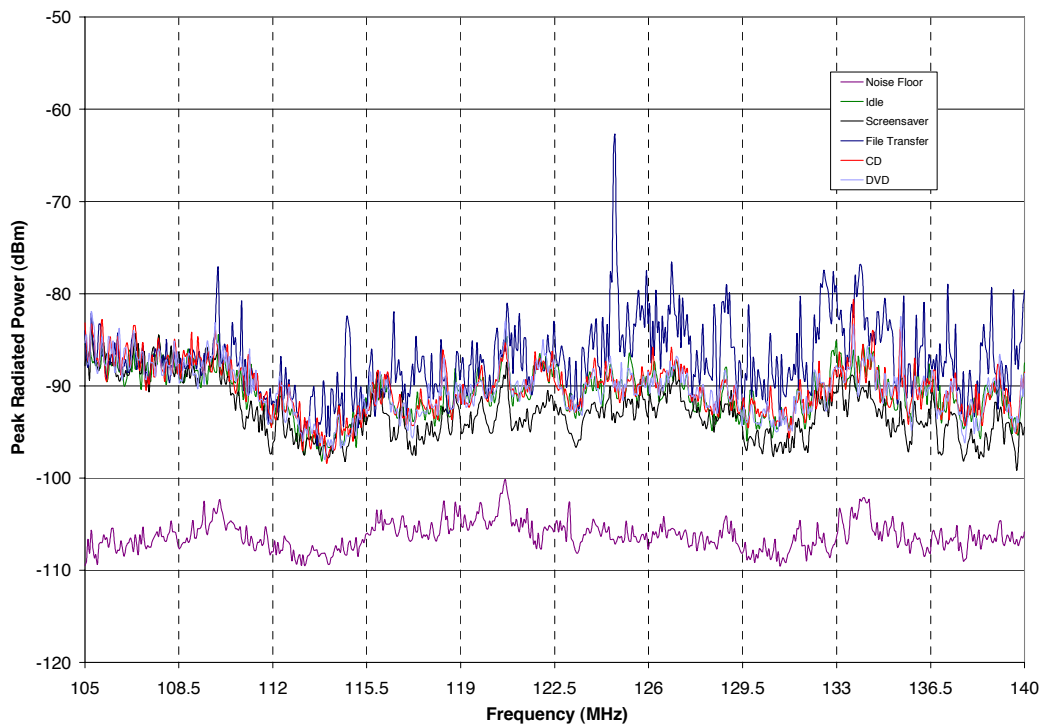


Figure B3: Laptop 9, Band 1b.

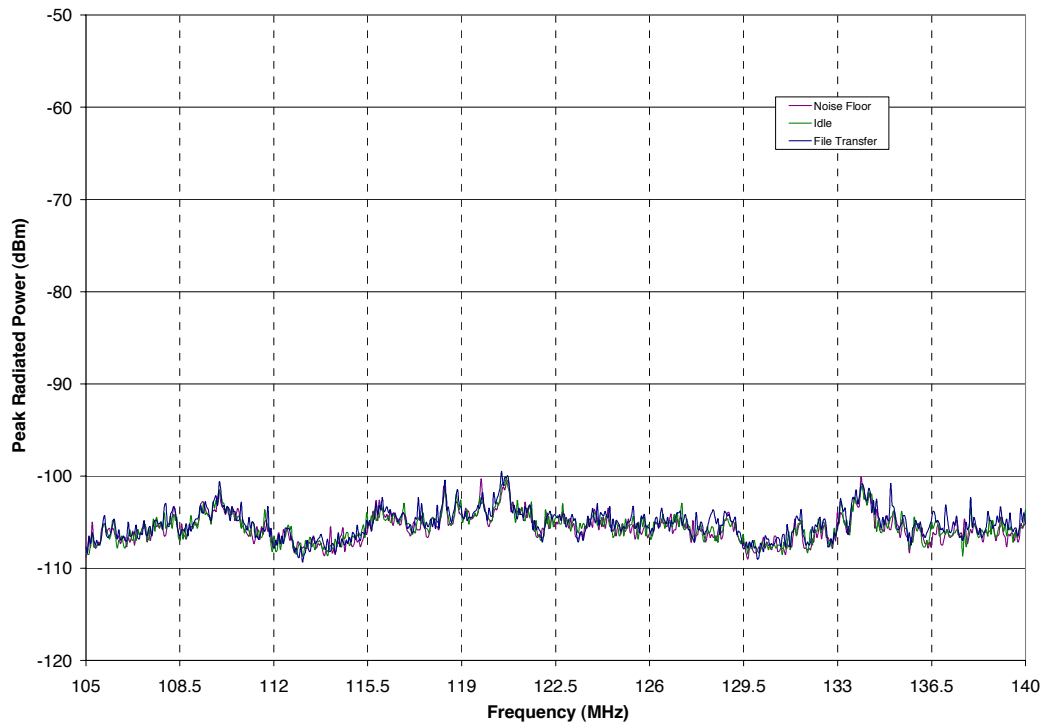


Figure B4: PDA 1, Band 1b.

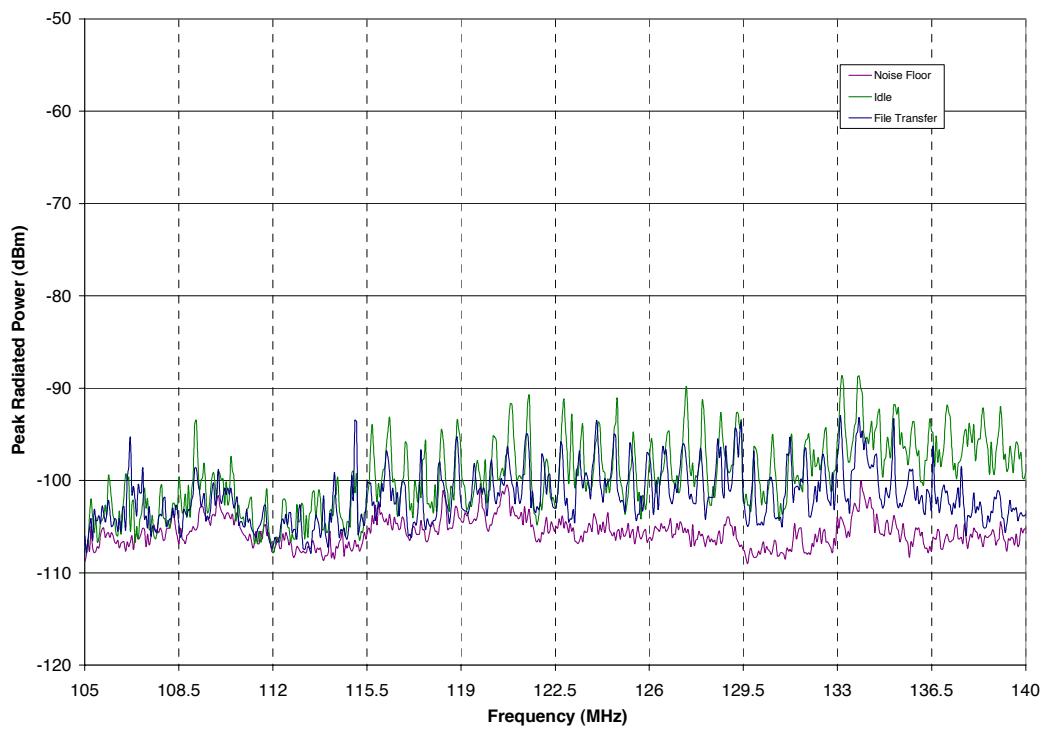


Figure B5: PDA 3, Band 1b.

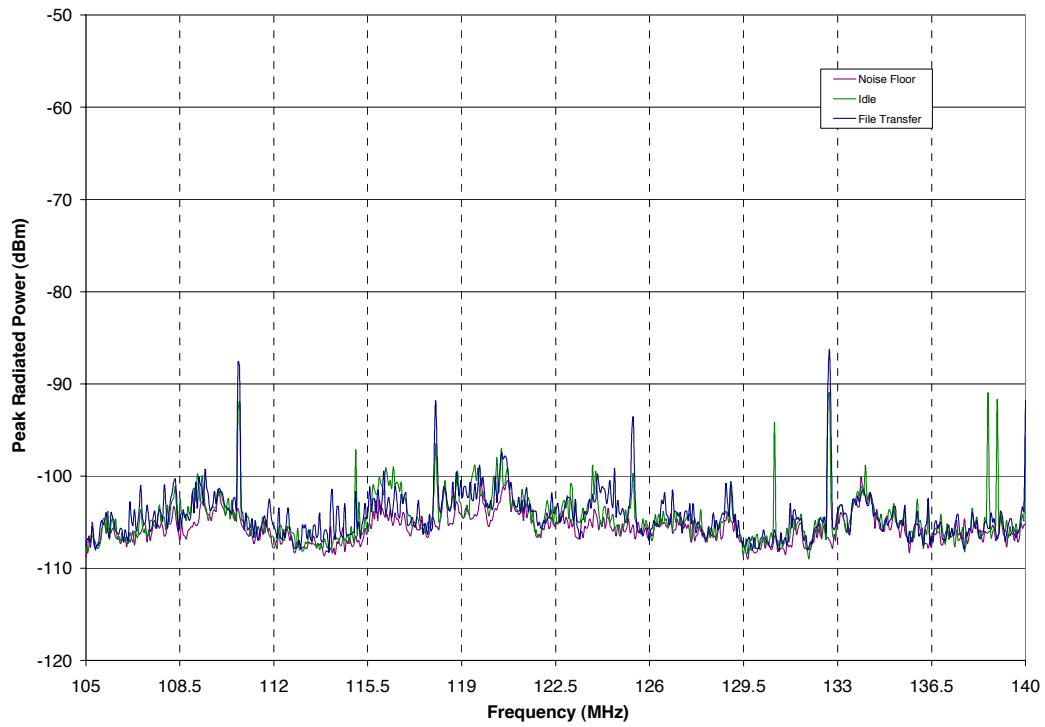


Figure B6: PDA 4, Band 1b.

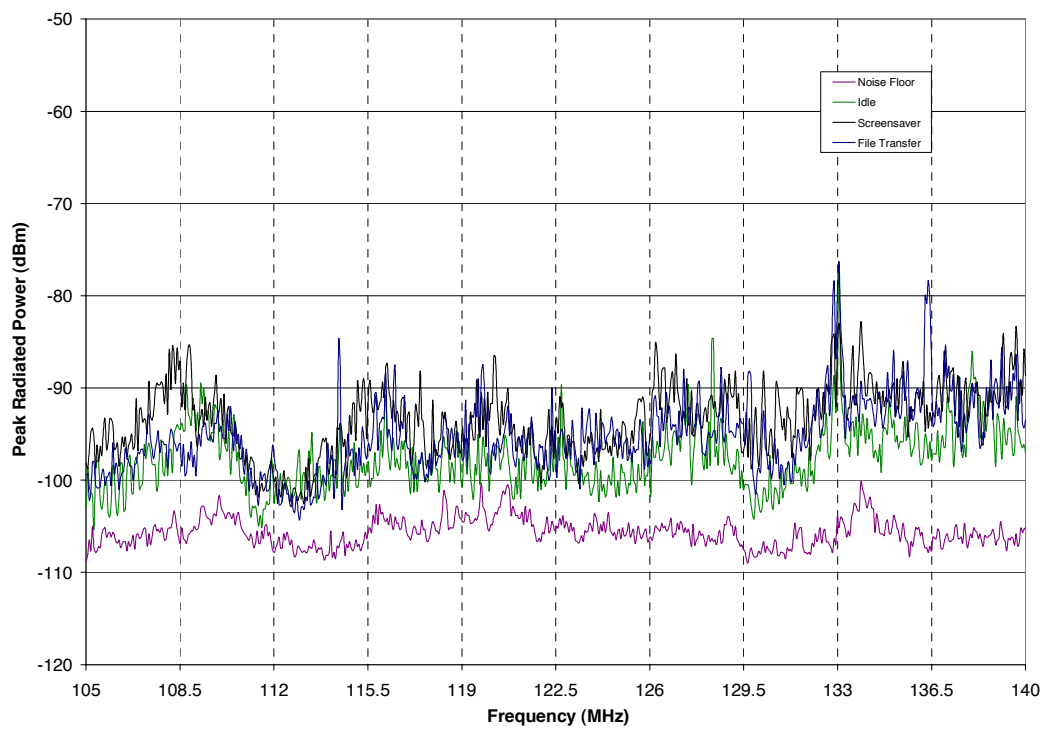


Figure B7: Tablet PC 1, Band 1b.

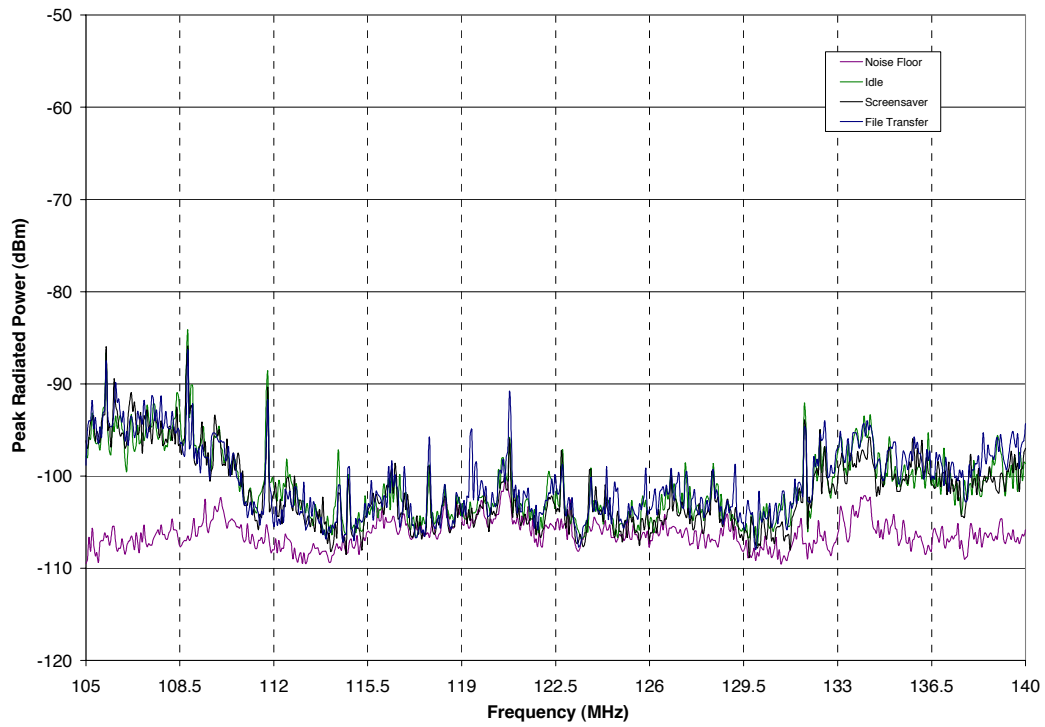


Figure B8: Tablet PC 2, Band 1b.

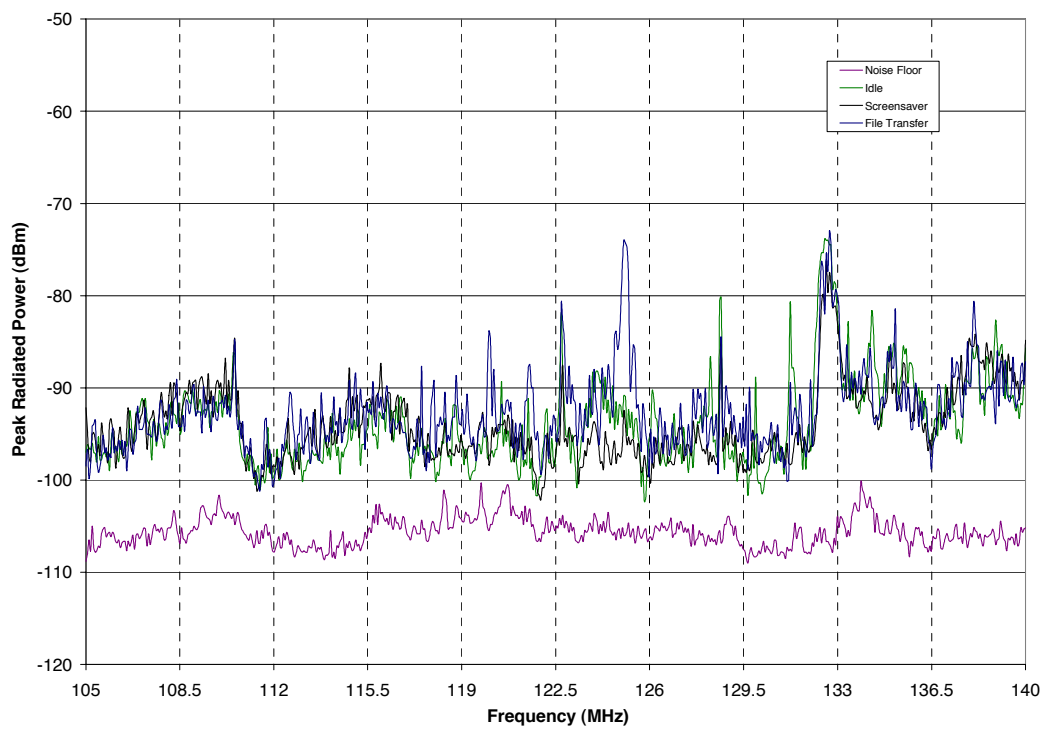


Figure B9: Tablet PC 3, Band 1b.

B.2 Band 2

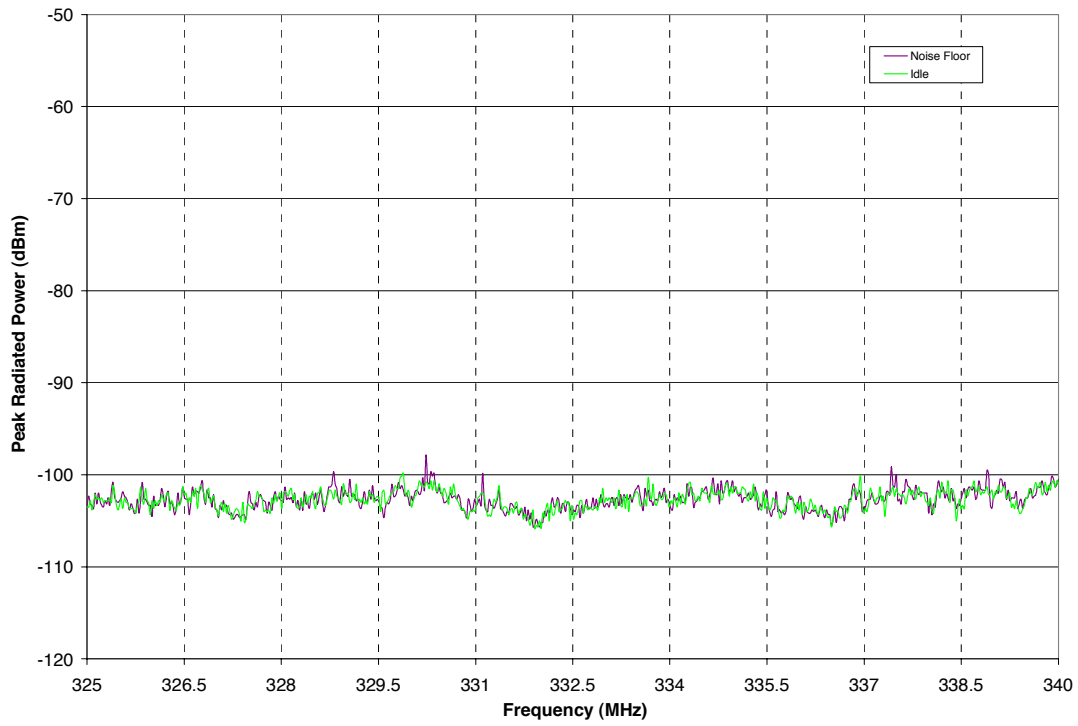


Figure B10: GPS 1, Band 2.

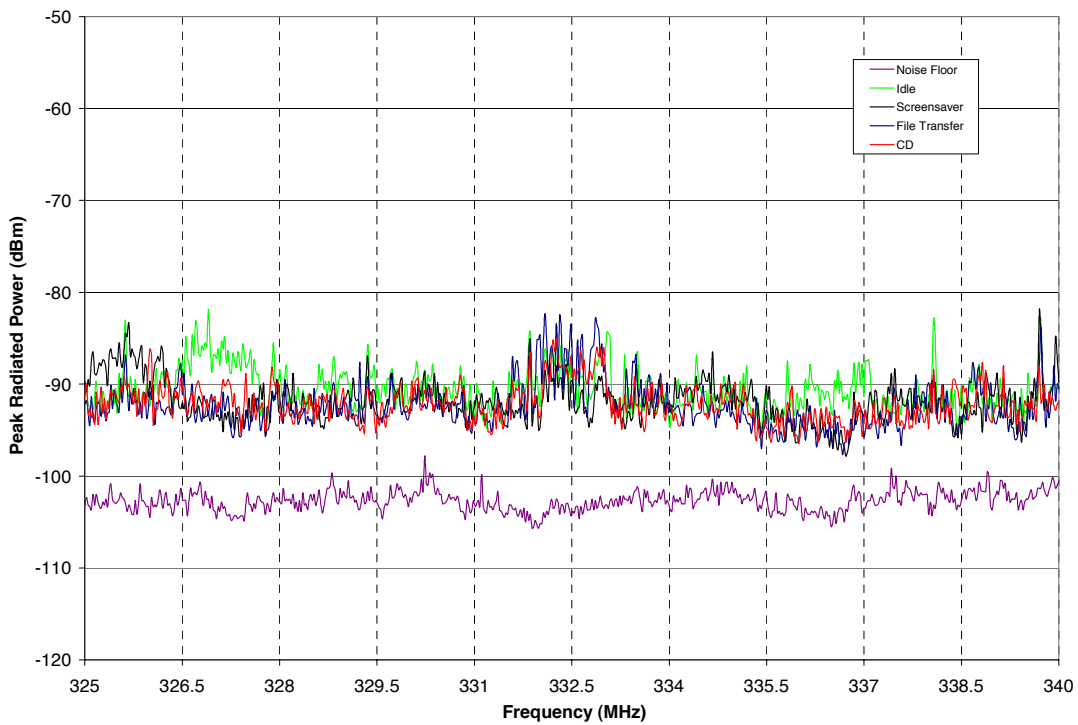


Figure B11: Laptop 4, Band 2.

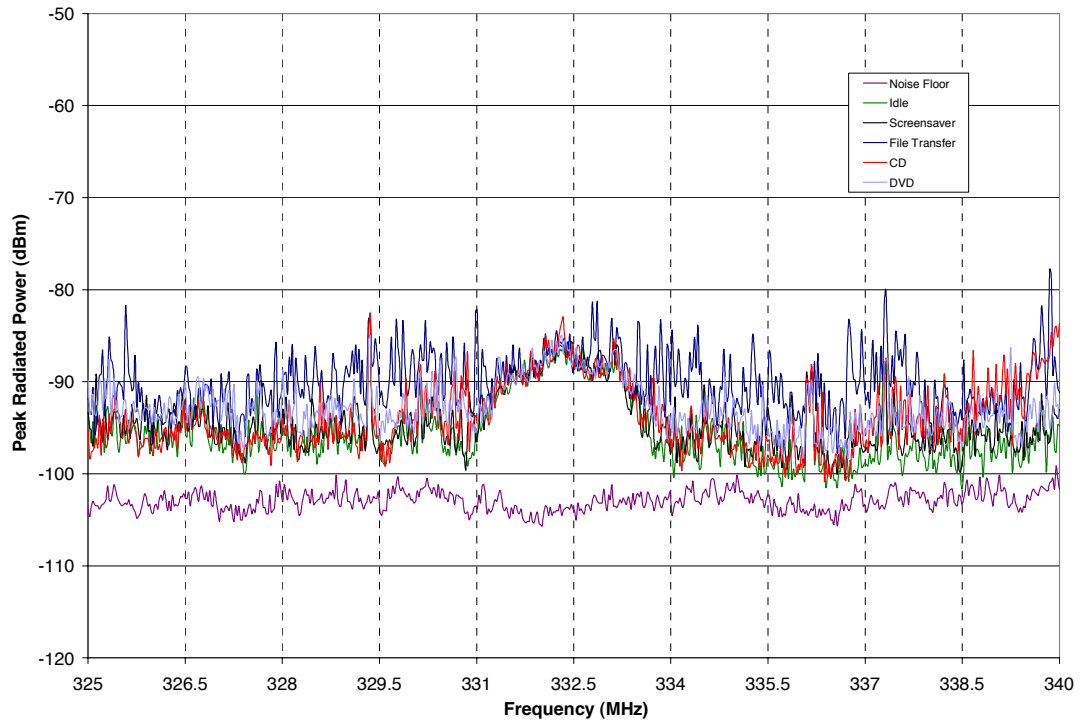


Figure B12: Laptop 9, Band 2.

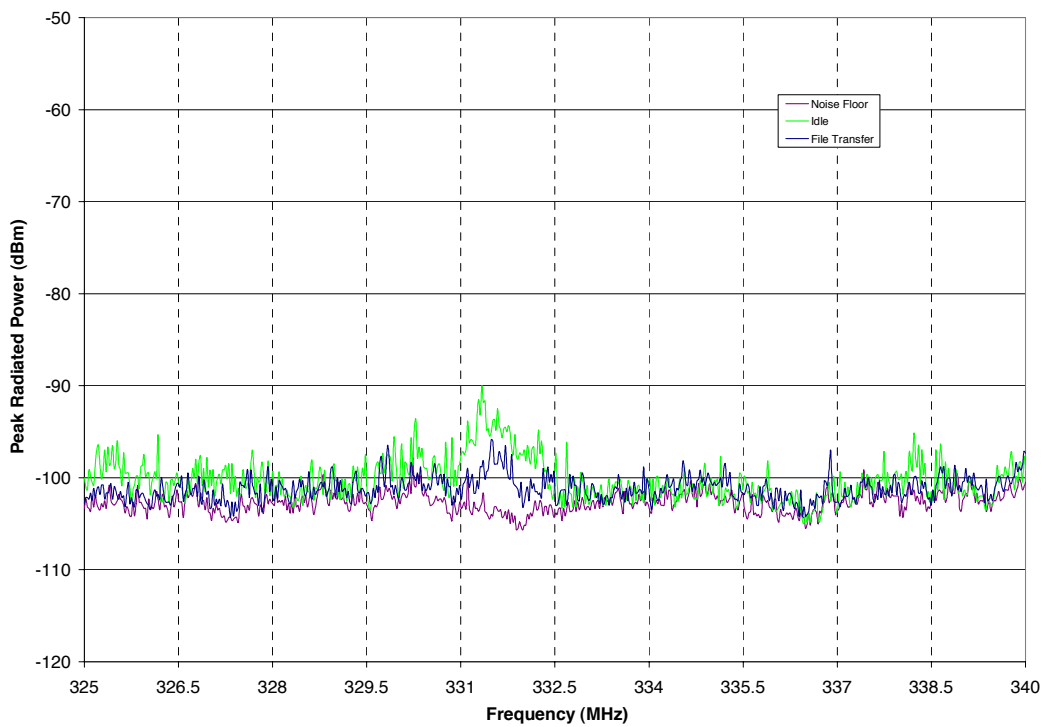


Figure B13: PDA 1, Band 2.

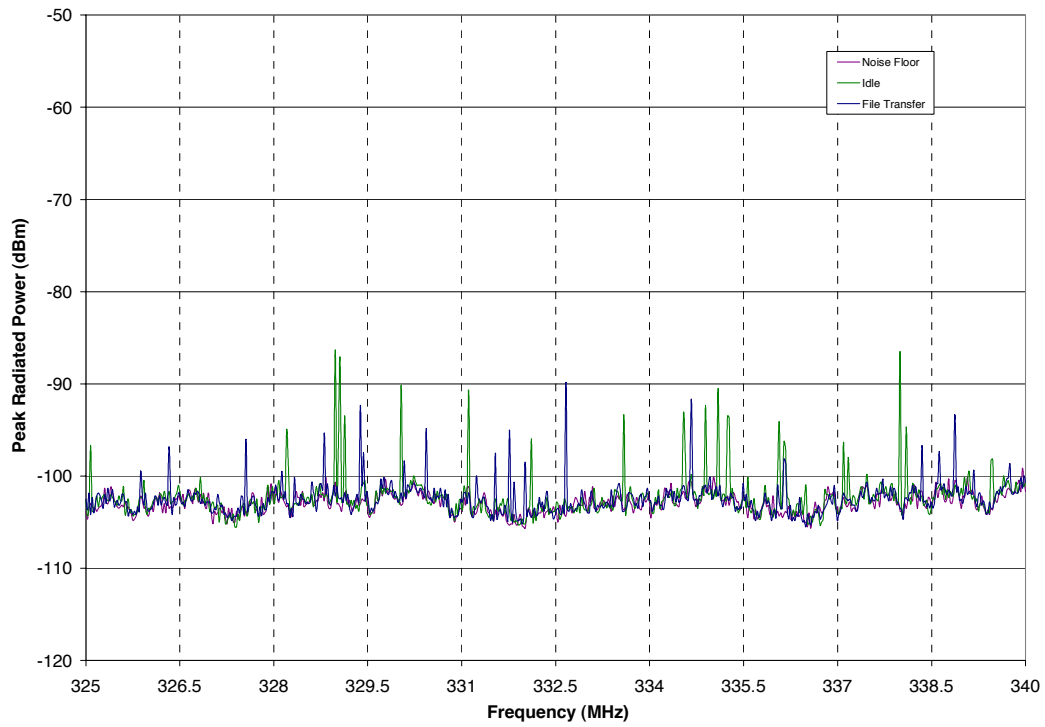


Figure B14: PDA 3, Band 2.

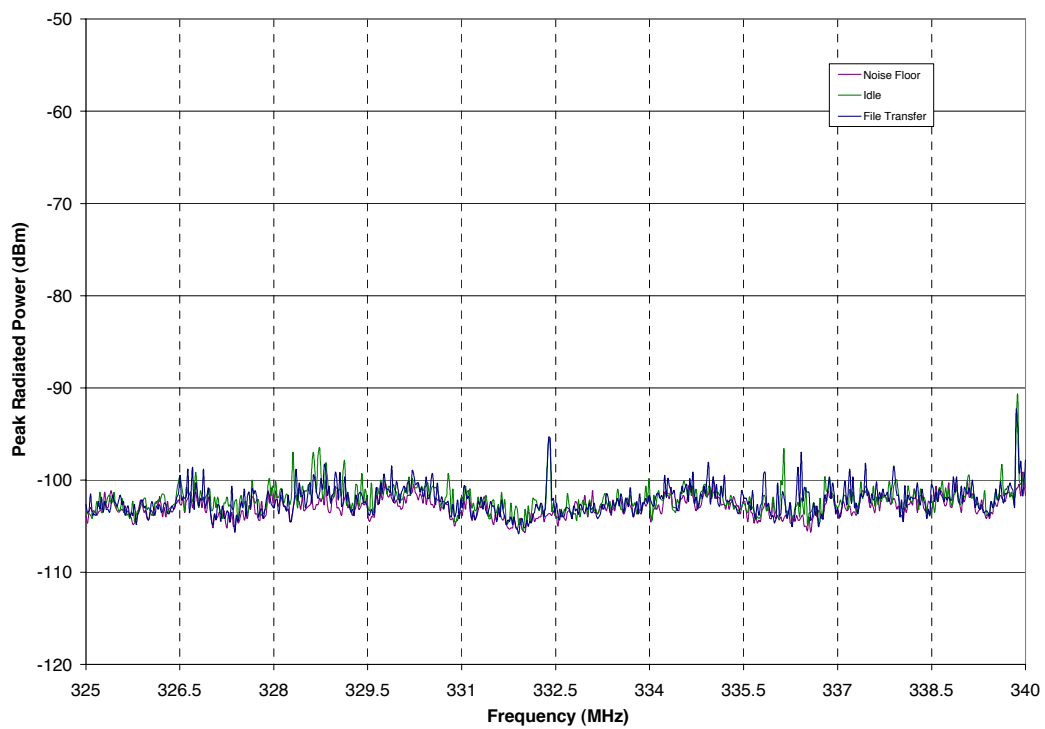


Figure B15: PDA 4, Band 2.

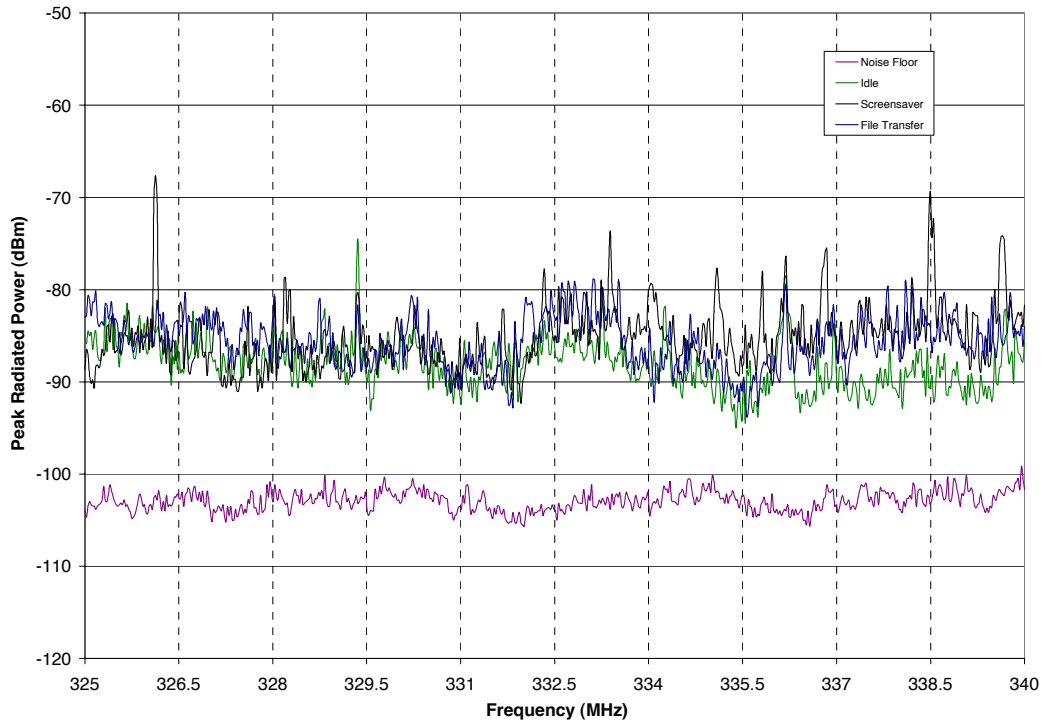


Figure B16: Tablet PC 1, Band 2.

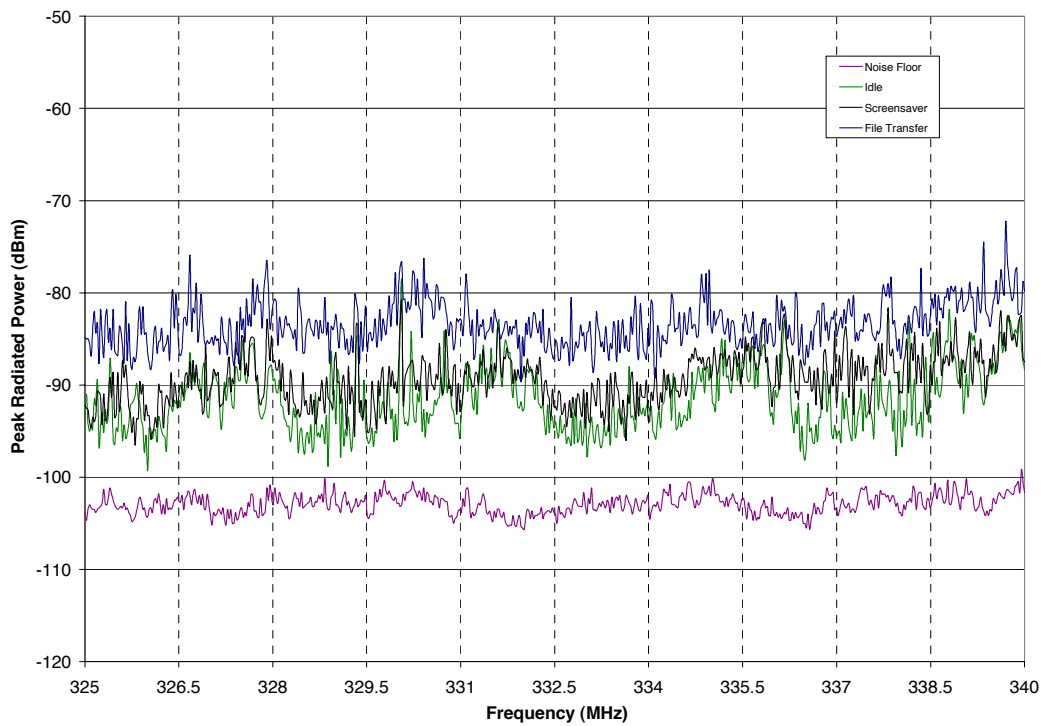


Figure B17: Tablet PC 2, Band 2.

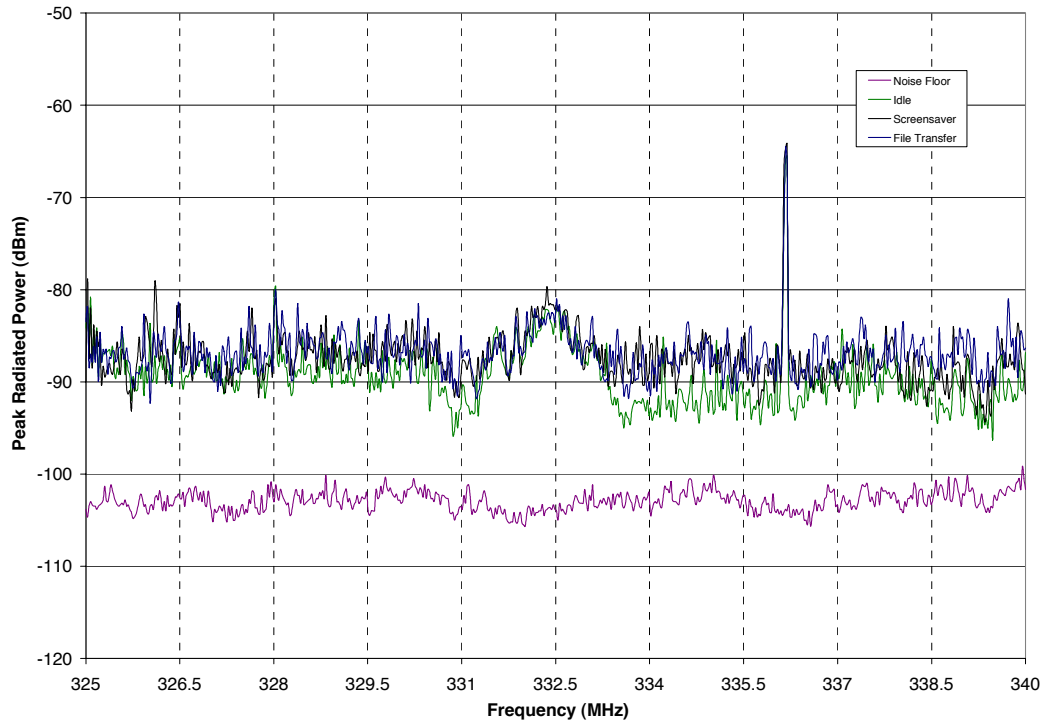


Figure B18: Tablet PC 3, Band 2.

B.3 Band 3

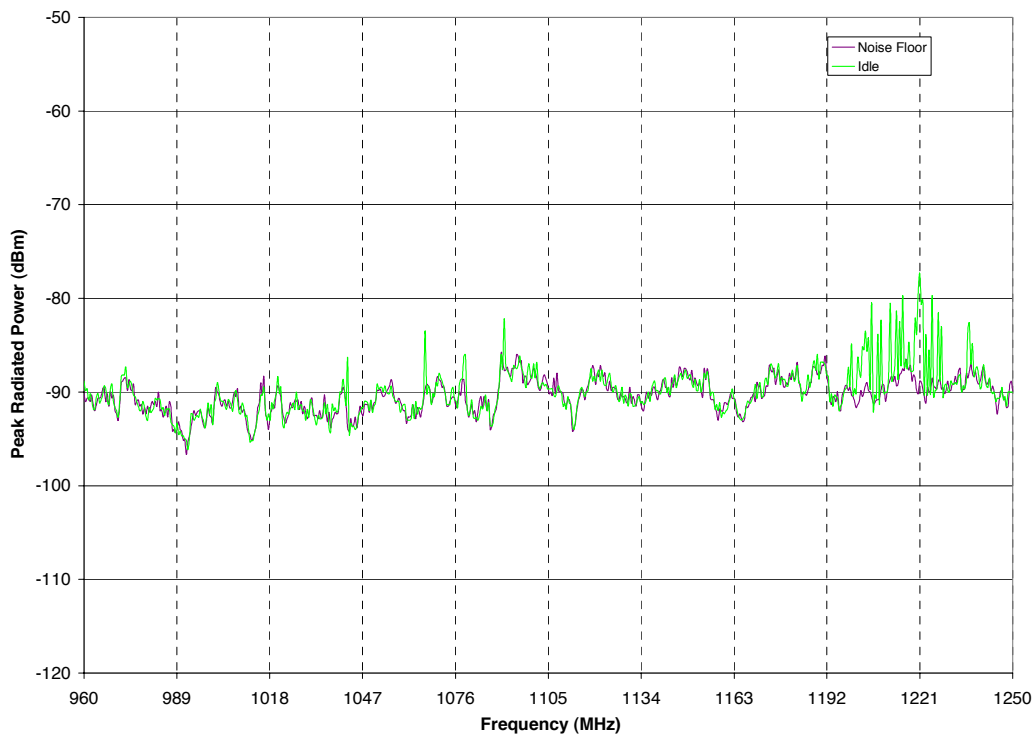


Figure B19: GPS 1, Band 3.

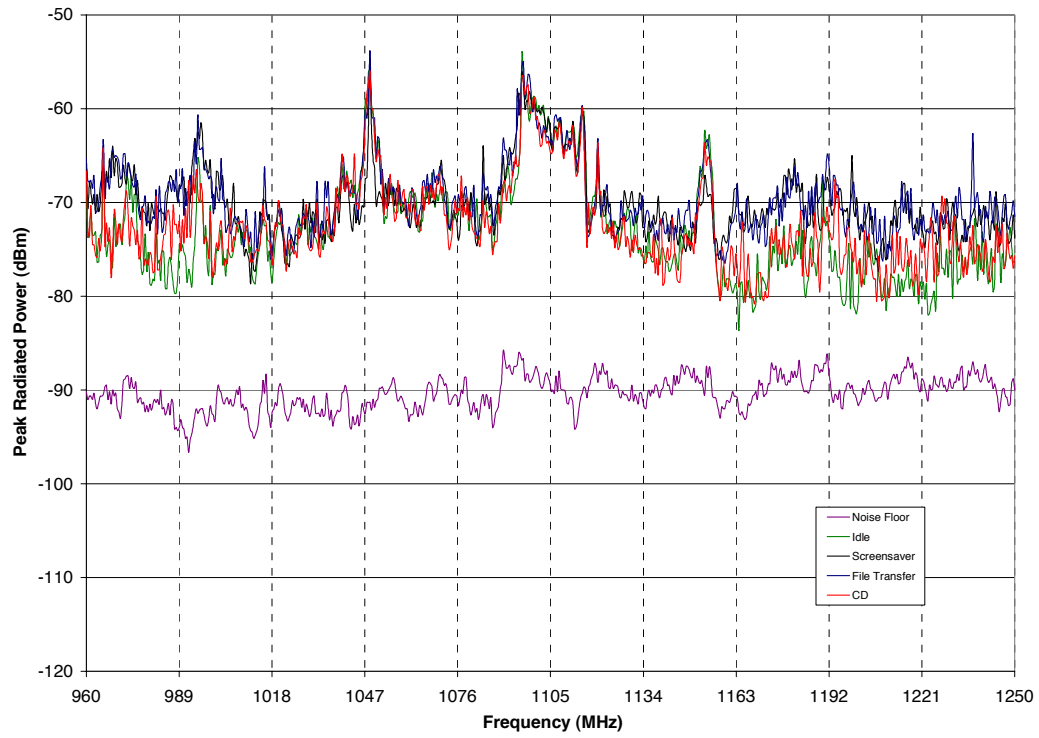


Figure B20: Laptop 4, Band 3

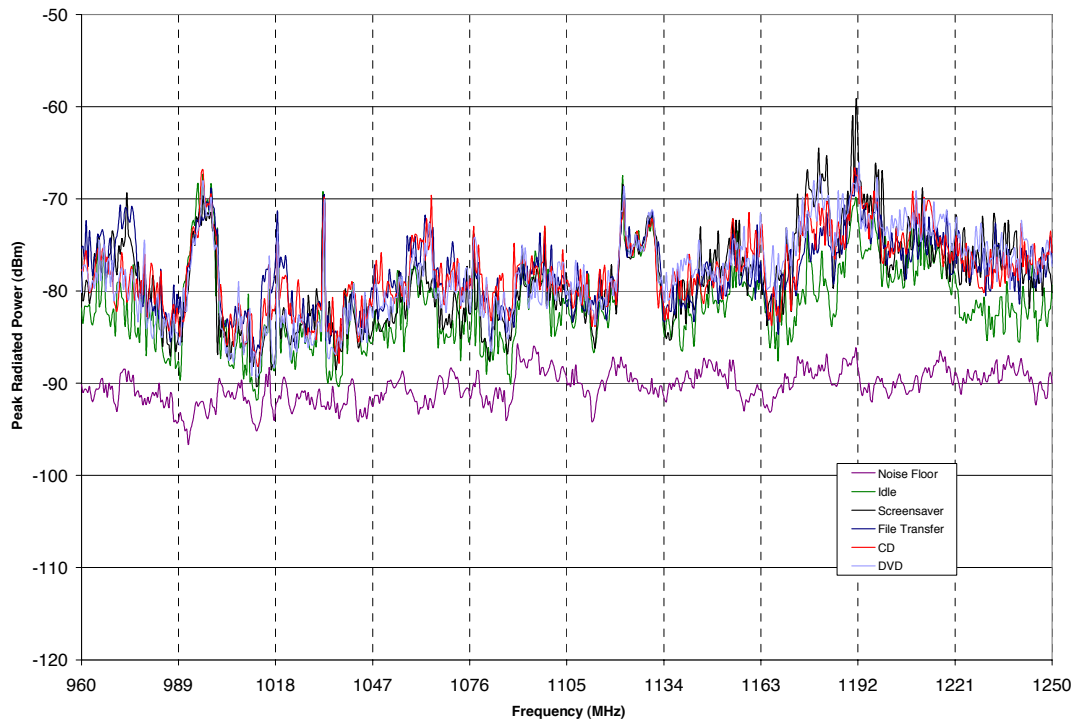


Figure B21: Laptop 9, Band 3.

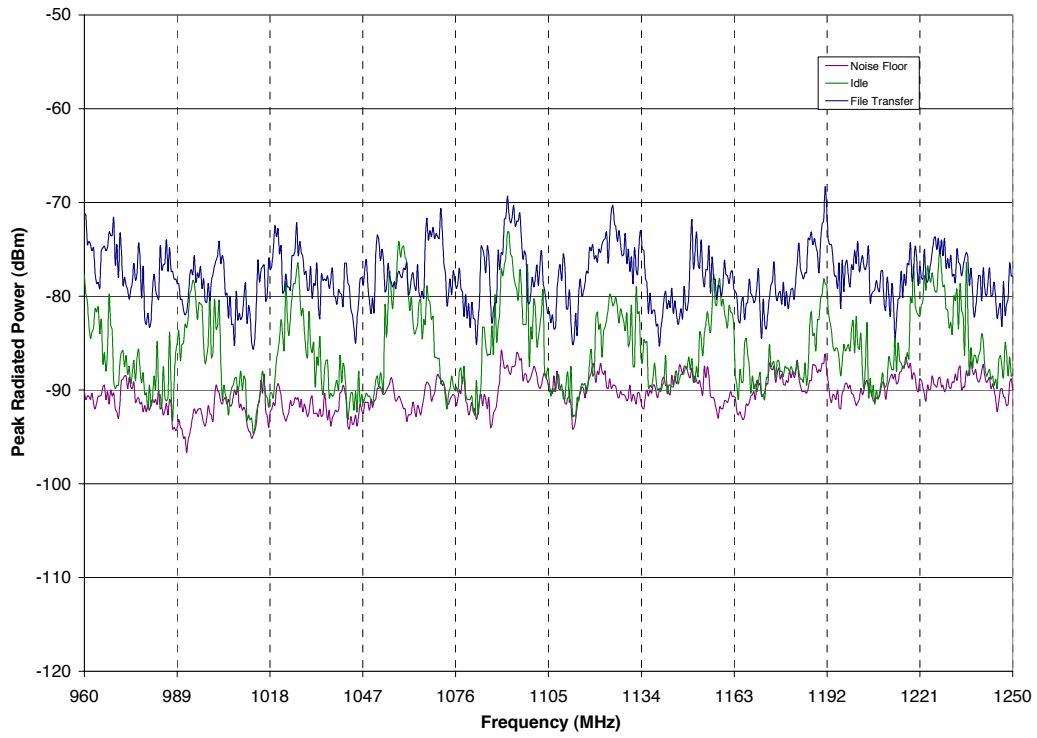


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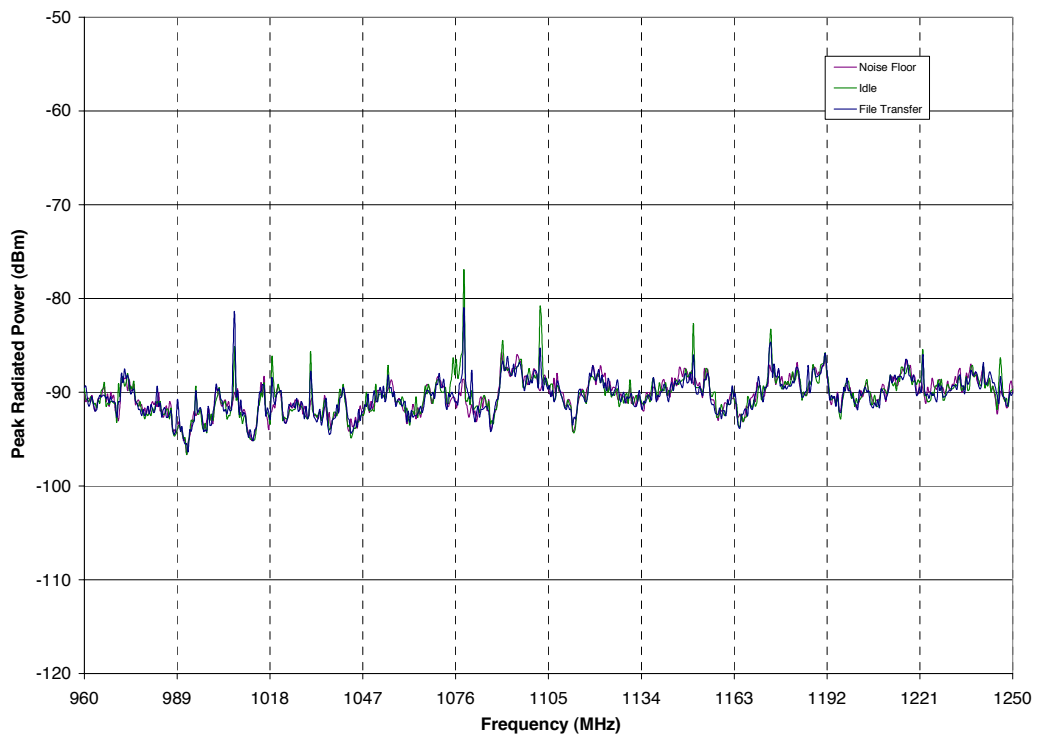


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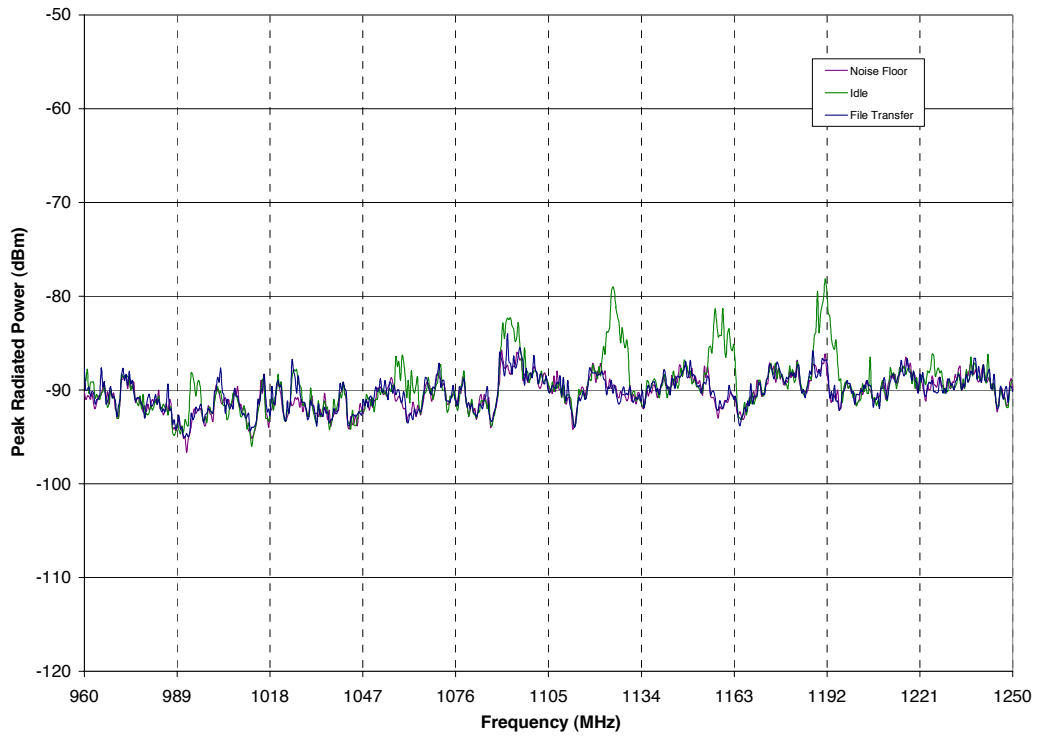


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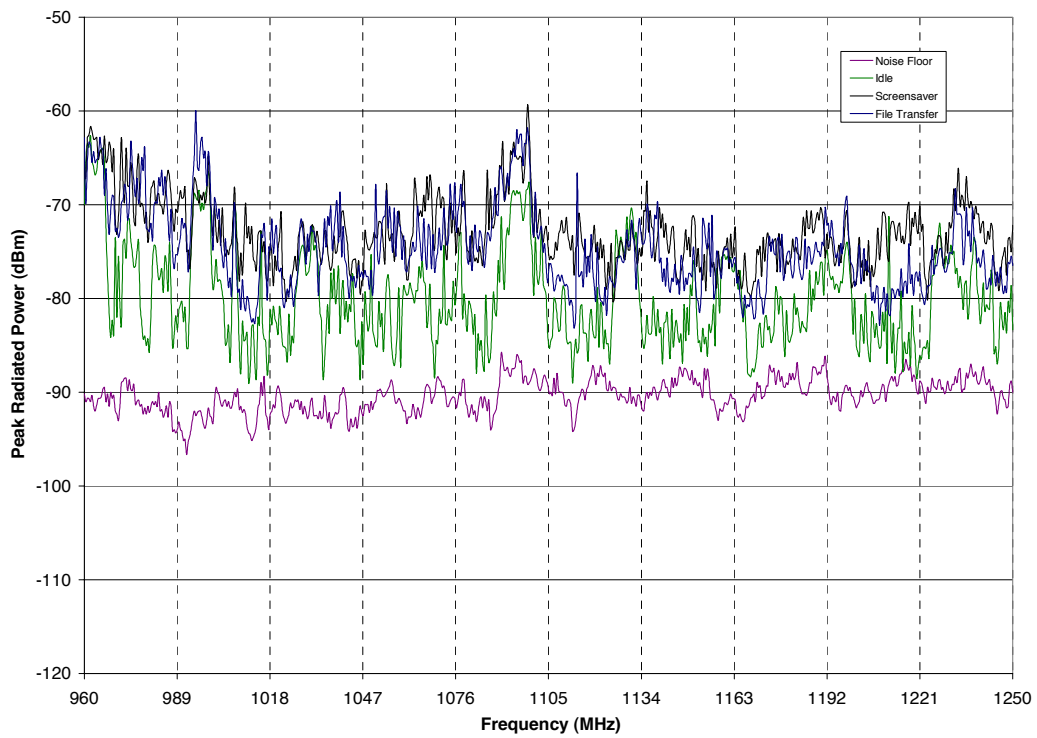


Figure B25: Tablet PC 1, Band 3.

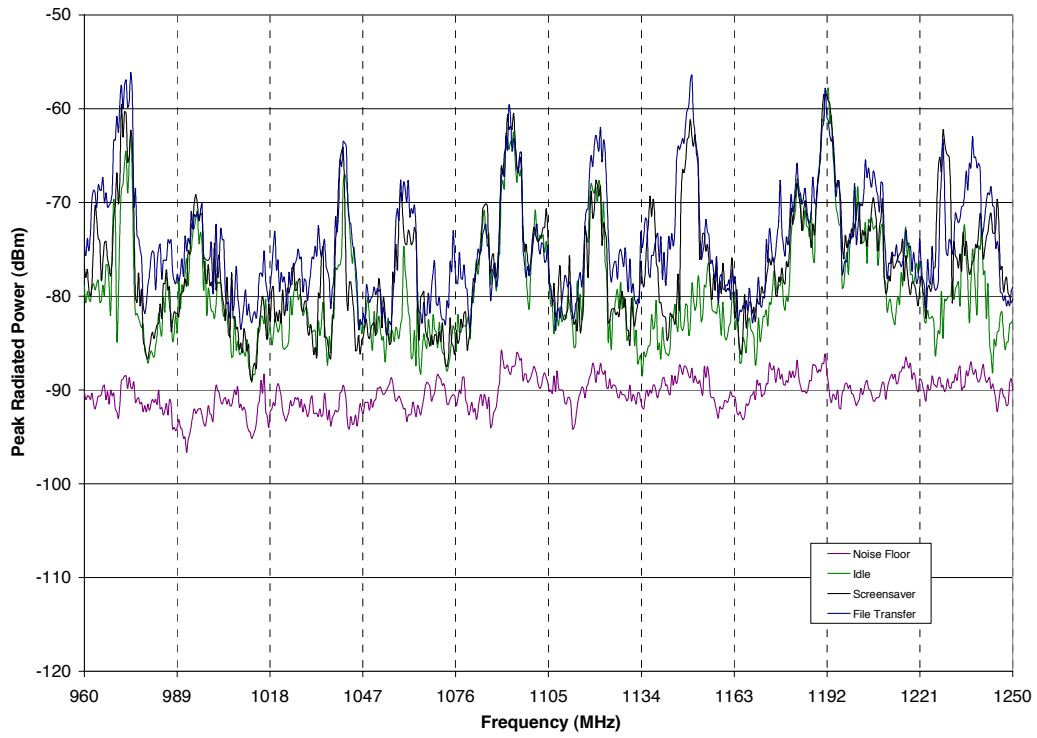


Figure B26: Tablet PC 2, Band 3.

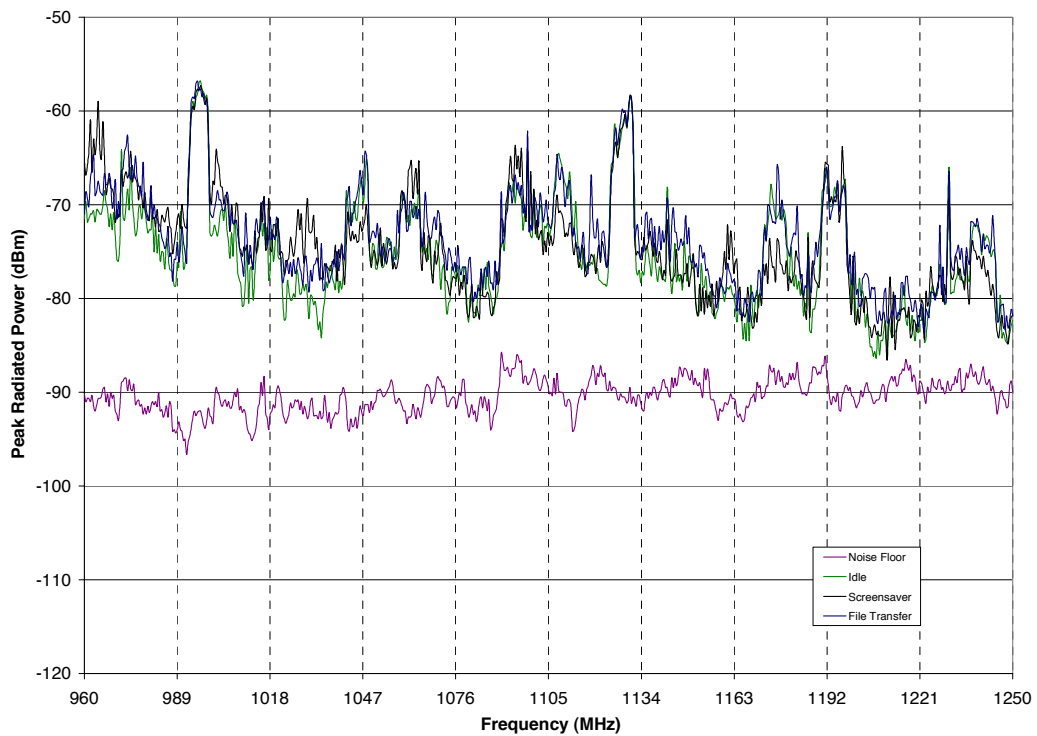


Figure B27: Tablet PC 3, Band 3.

B.4 Band 4

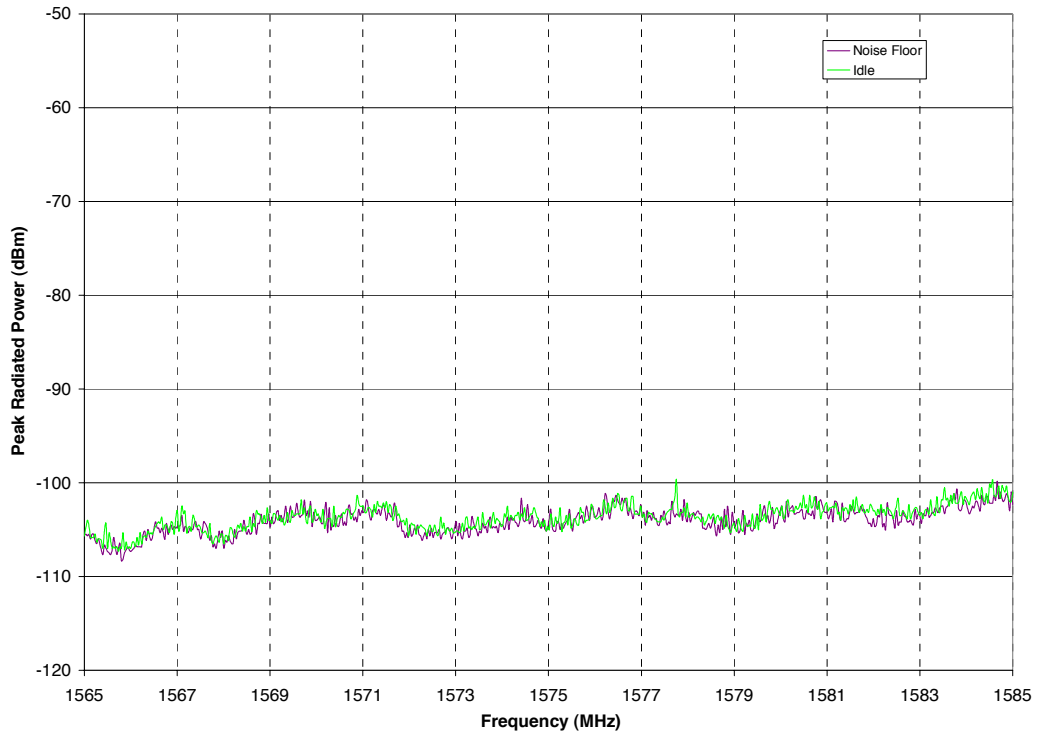


Figure B28: GPS 1, Band 4.

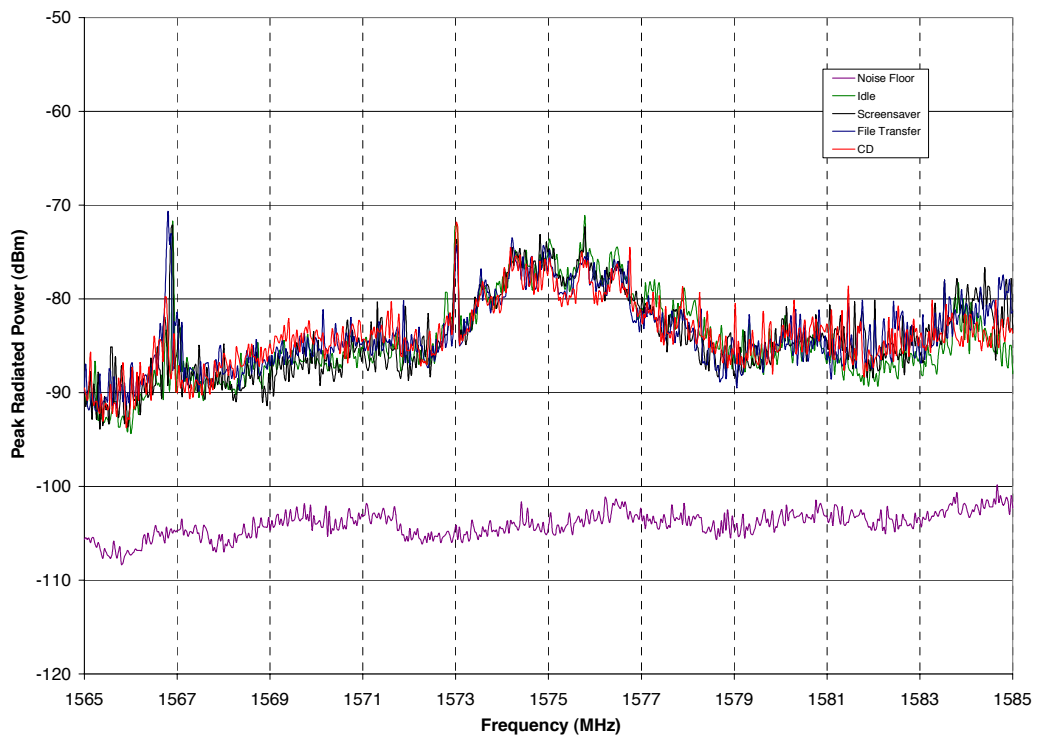


Figure B29: Laptop 4, Band 4.

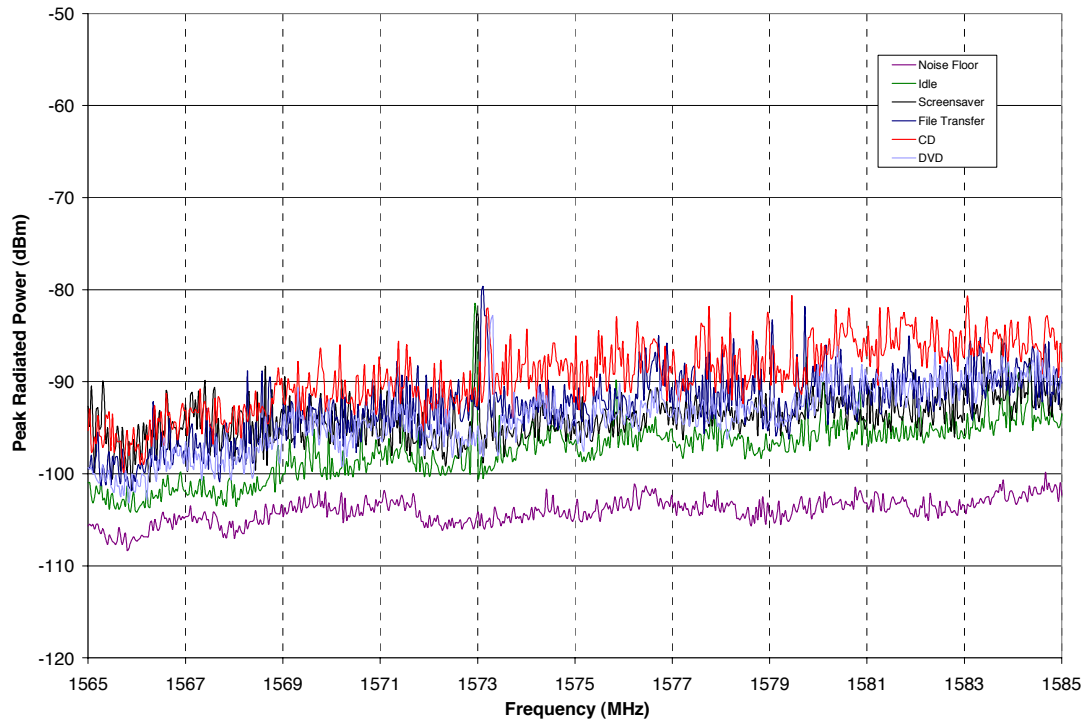


Figure B30: Laptop 9, Band 4.

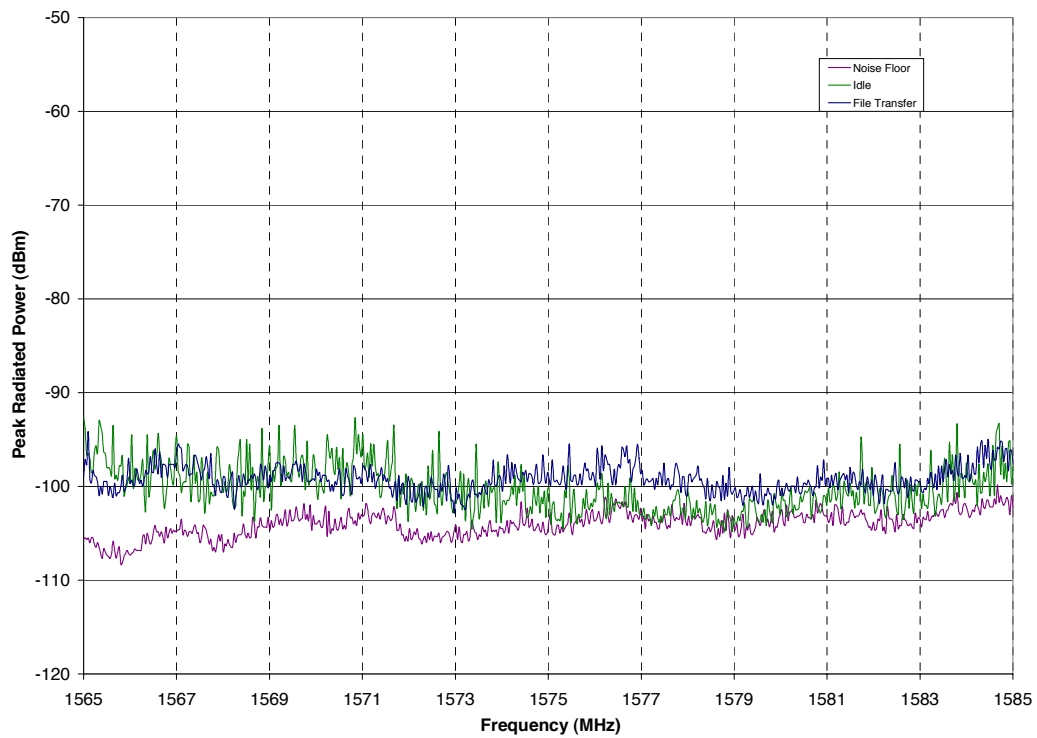


Figure B31: PDA 1, Band 4.

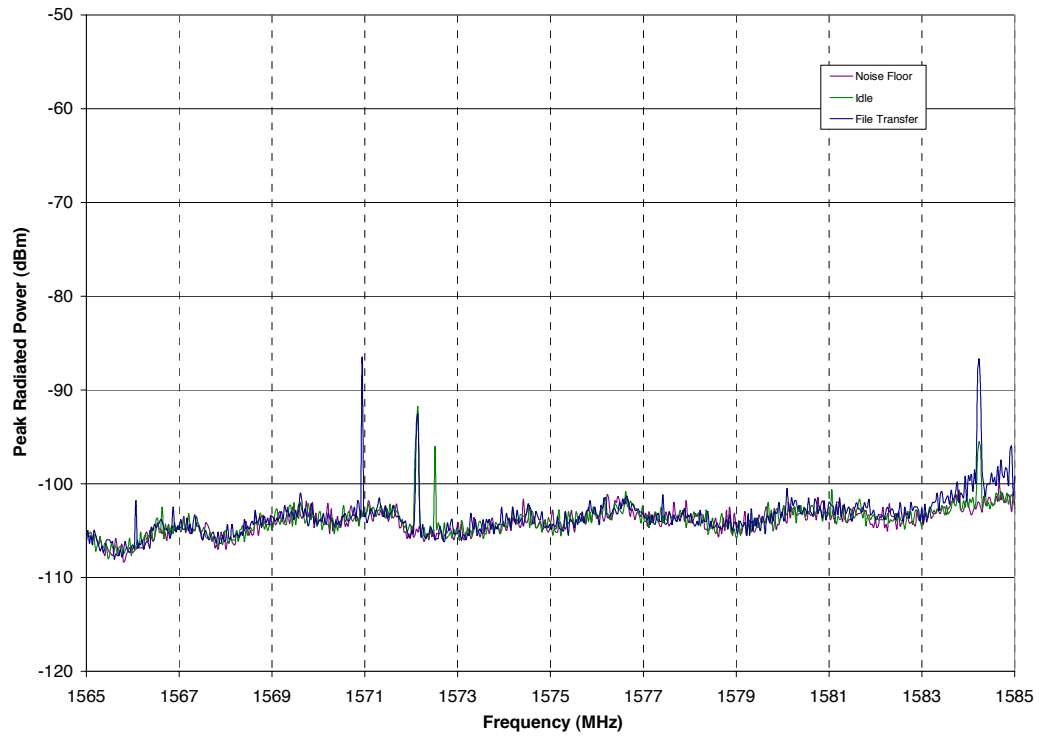


Figure B32: PDA 3, Band 4.

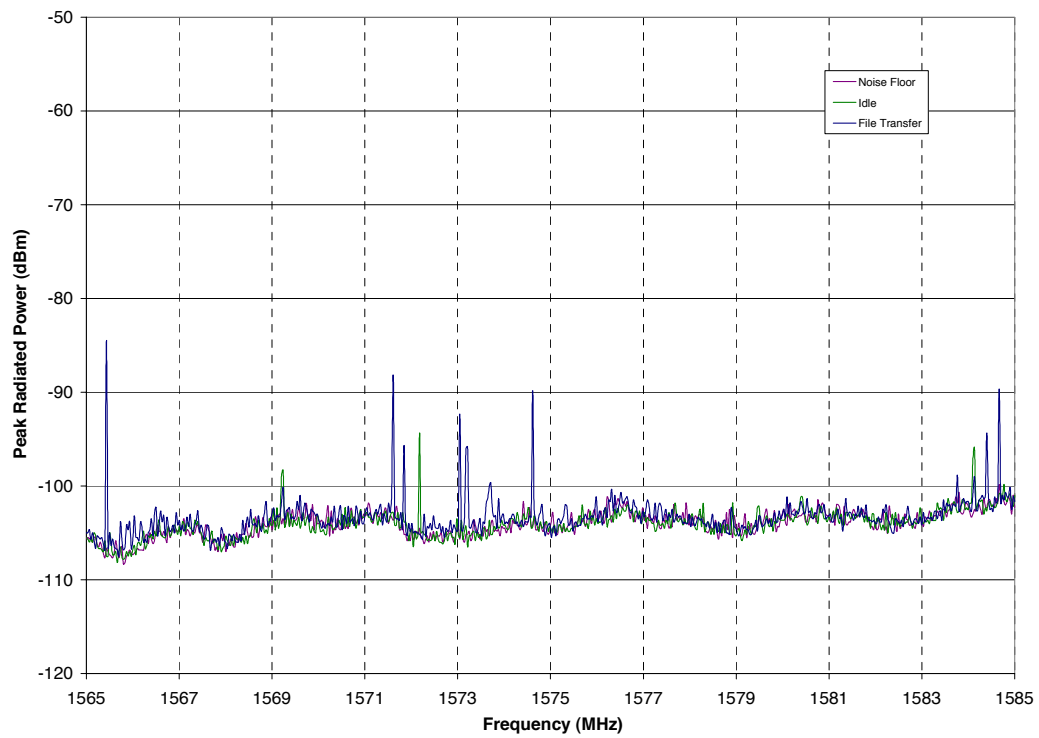


Figure B33: PDA 4, Band 4.

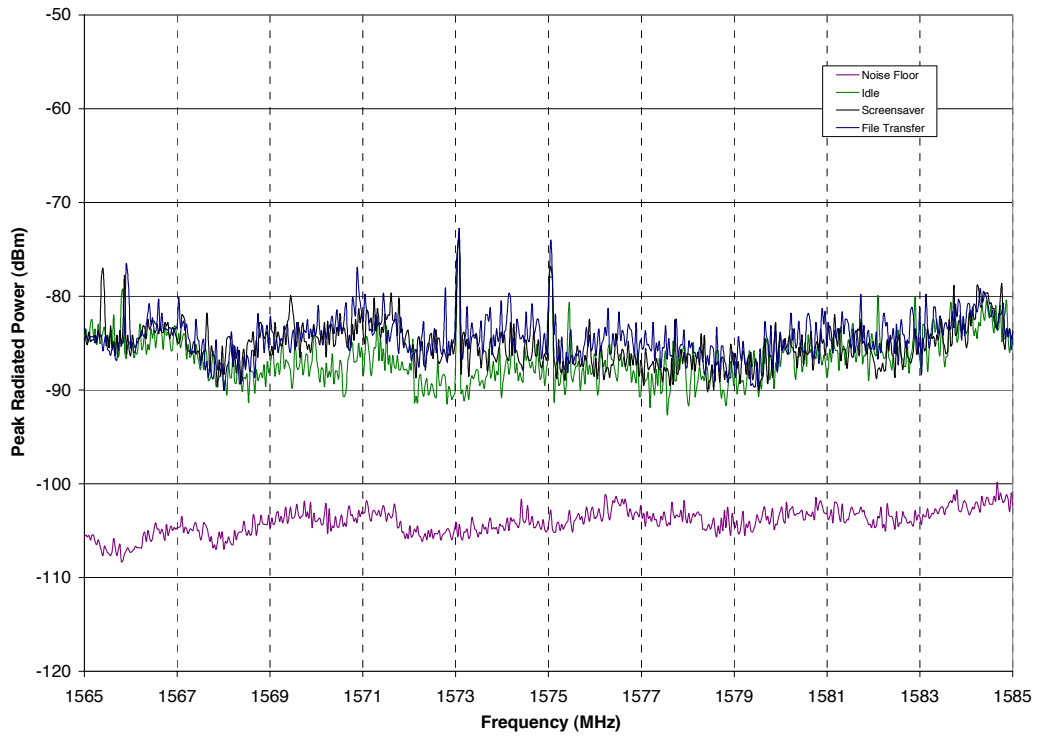


Figure B34: Tablet PC 1, Band 4.

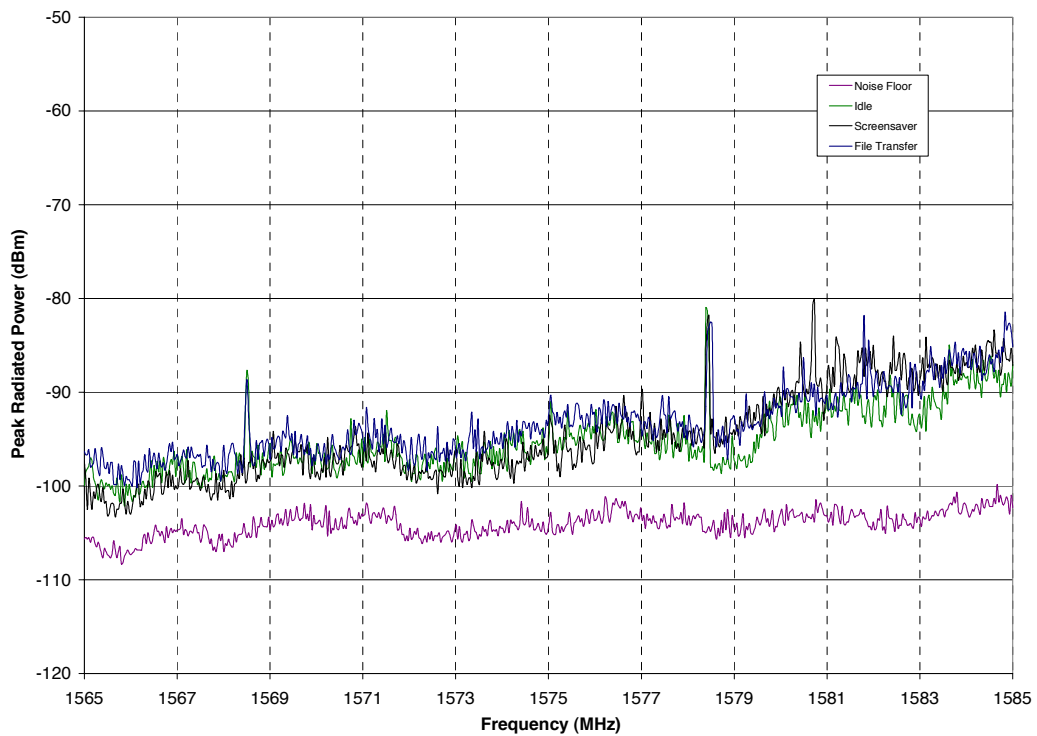


Figure B35: Tablet PC 2, Band 4.

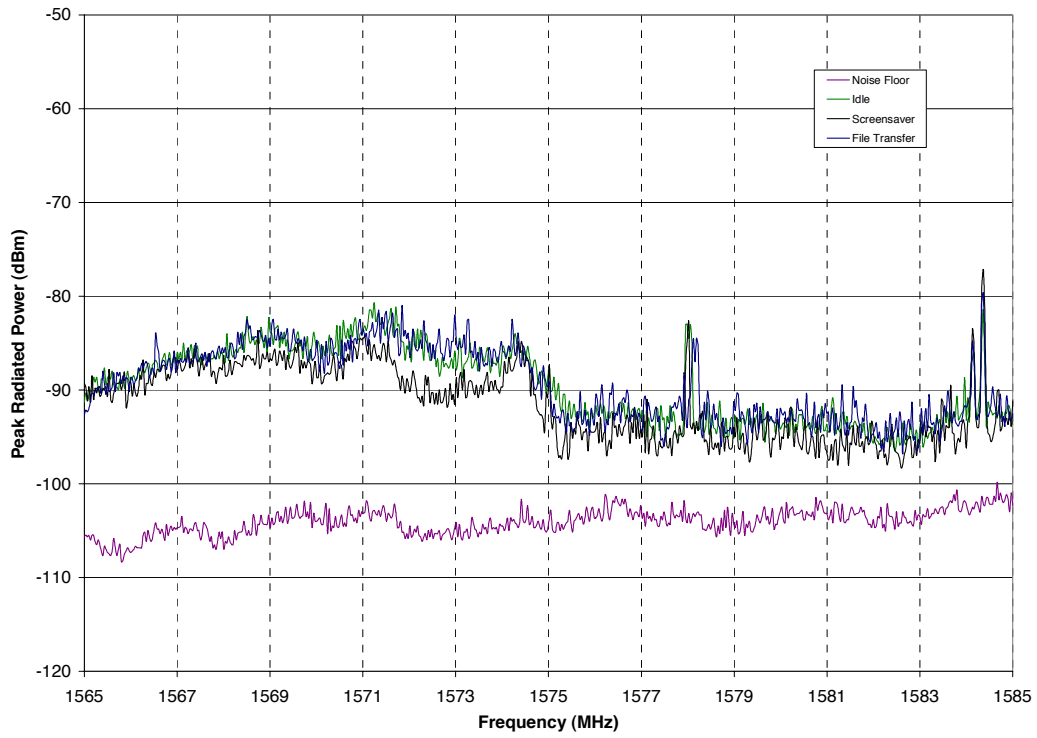


Figure B36: Tablet PC 3, Band 4.

B.5 Band 5

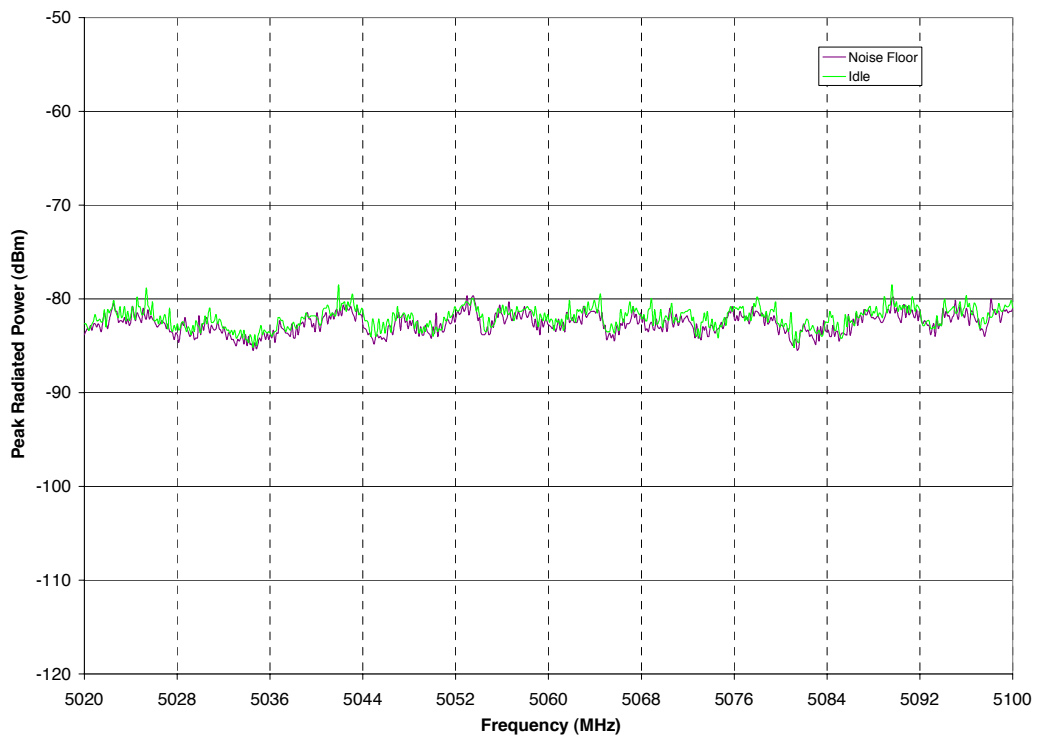


Figure B37: GPS 1, Band 5.

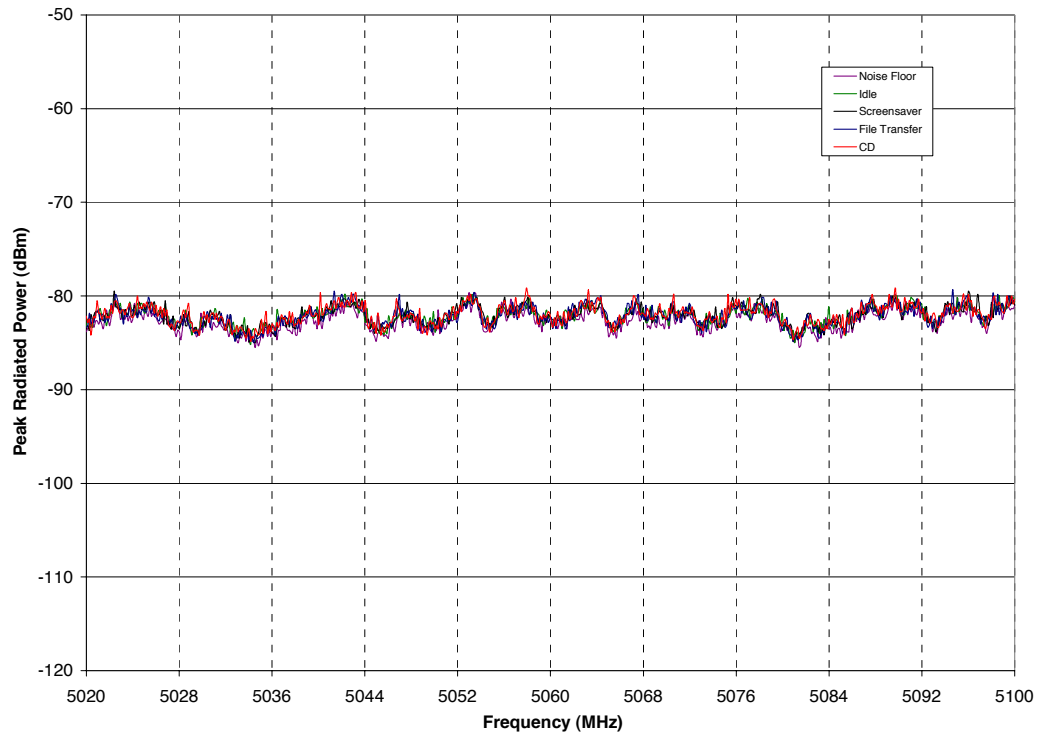


Figure B38: Laptop 4, Band 5.

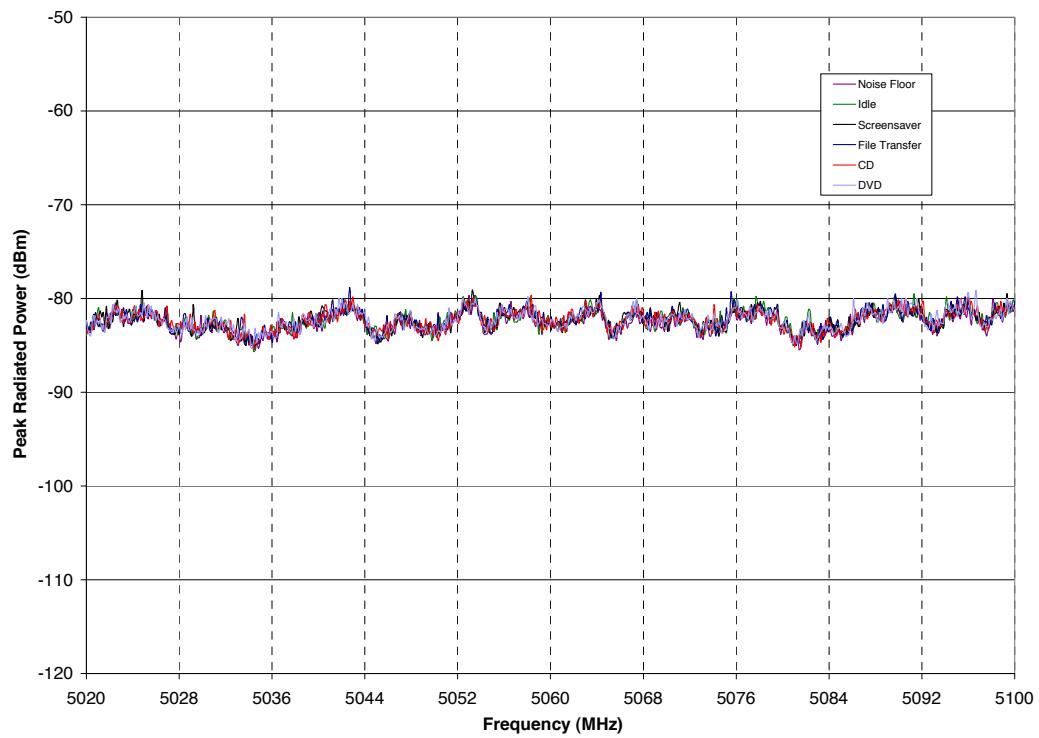


Figure B39: Laptop 9, Band 5.

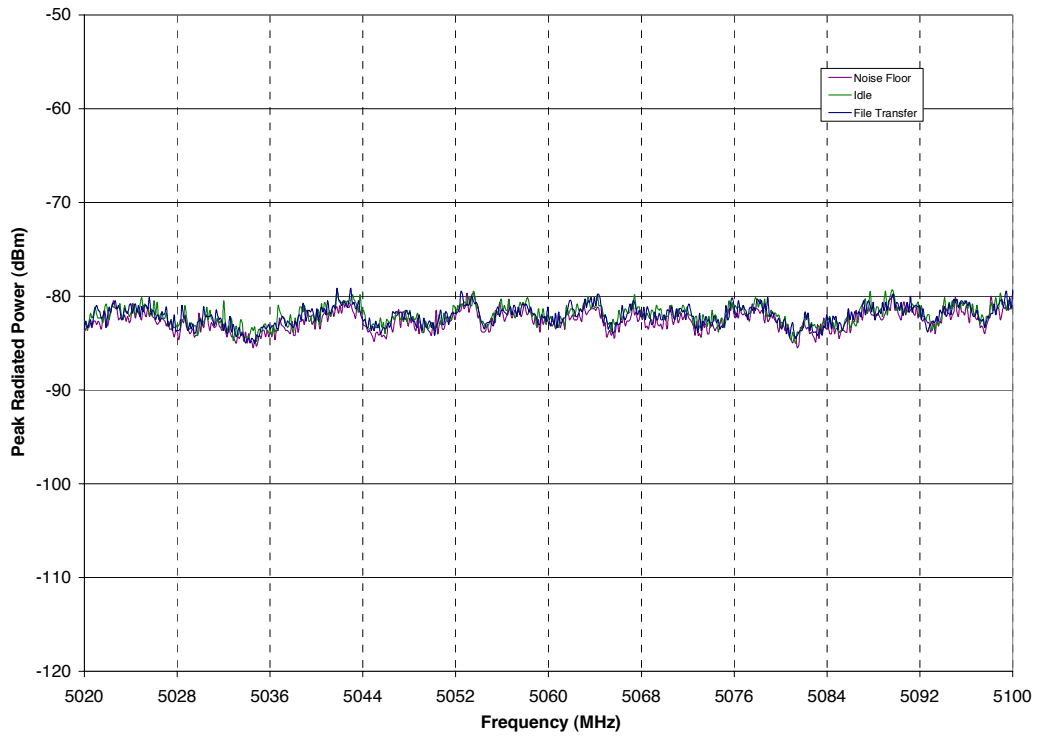


Figure B40: PDA 1, Band 5.

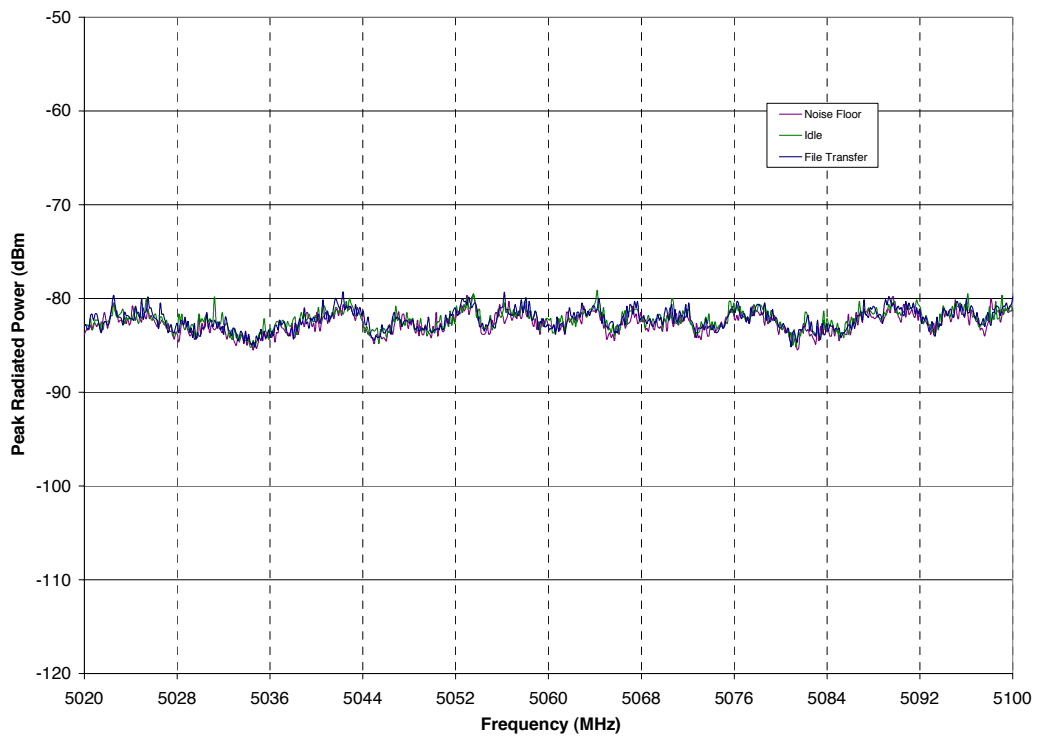


Figure B41: PDA 3, Band 5.

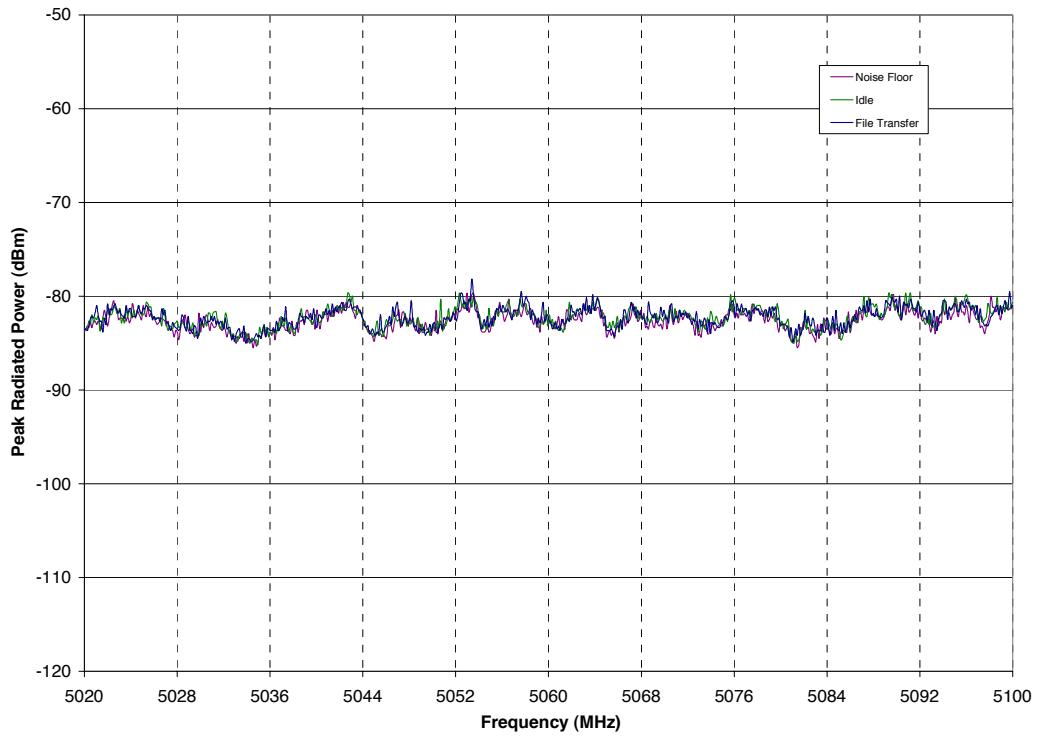


Figure B42: PDA 4, Band 5.

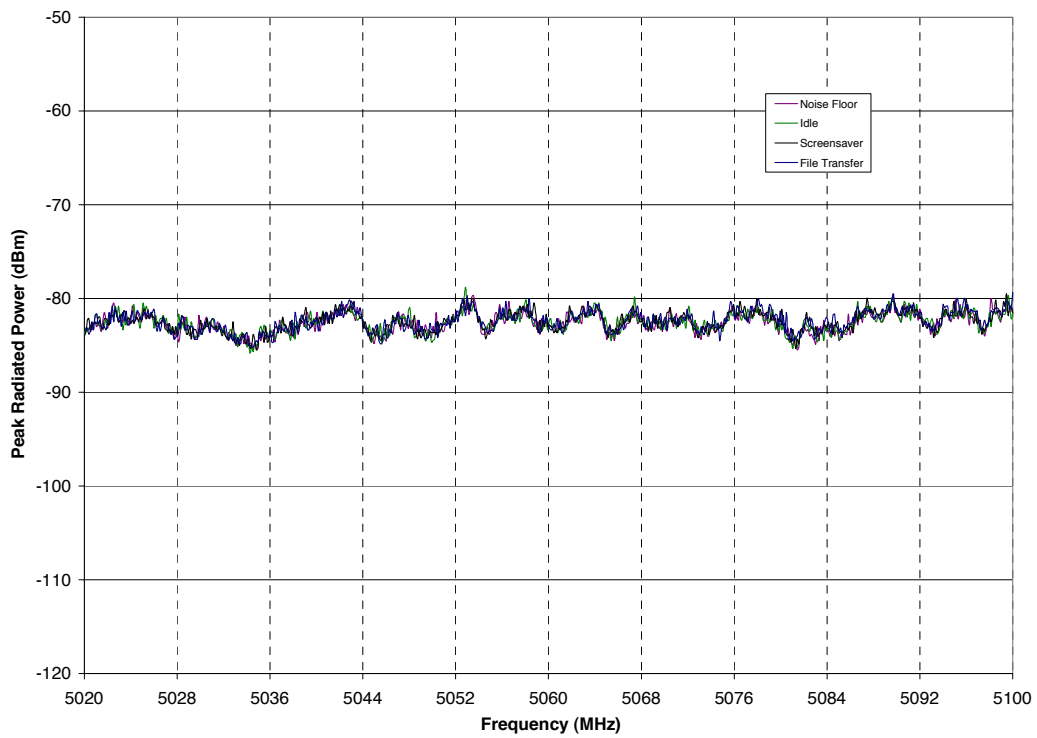


Figure B43: Tablet PC 1, Band 5.

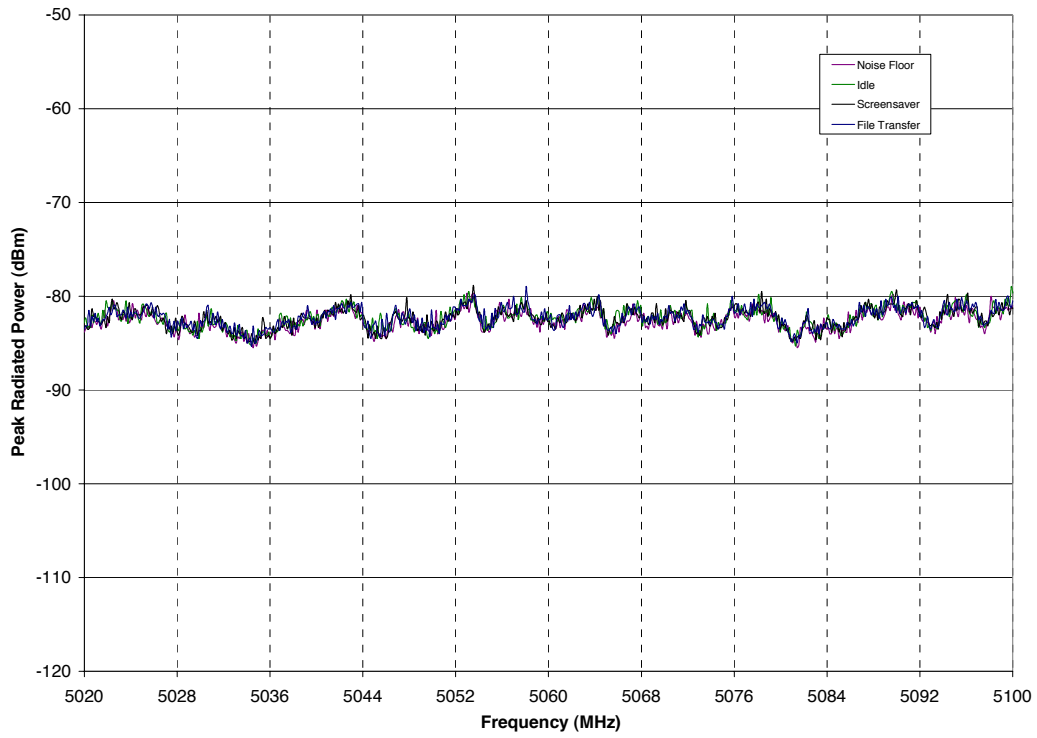


Figure B44: Tablet PC 2, Band 5.

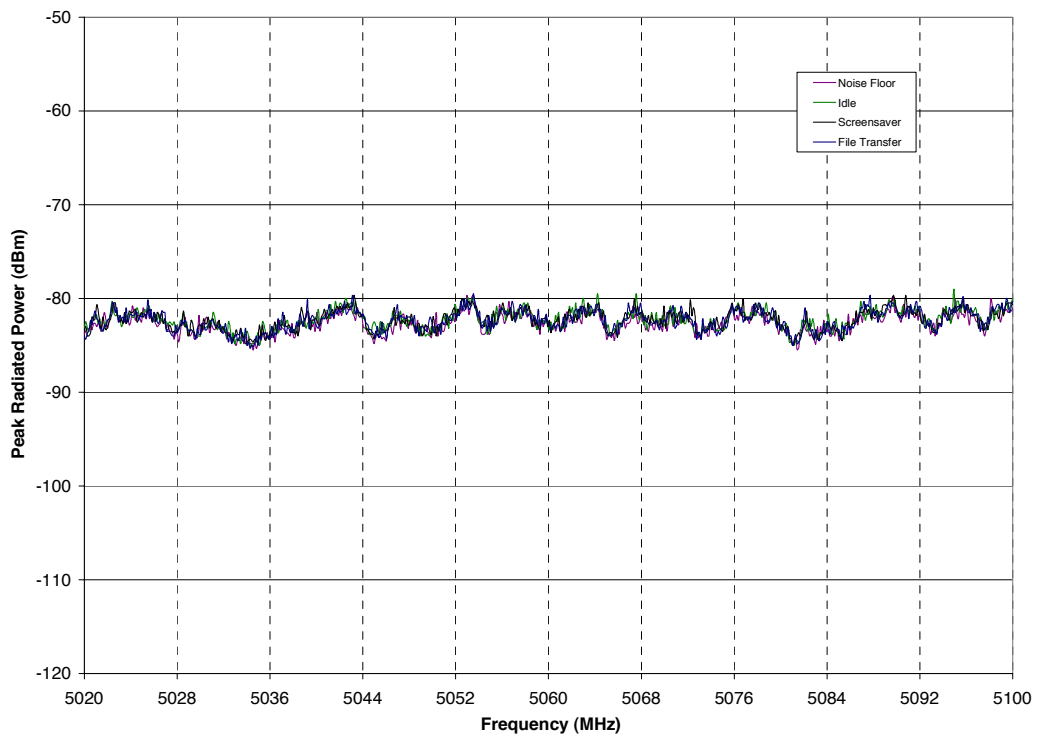


Figure B45: Tablet PC 3, Band 5.

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14. ABSTRACT An assessment was conducted on multiple wireless local area network (WLAN) devices using the three wireless standards for spurious radiated emissions to determine their threat to aircraft radio navigation systems. The measurement process, data and analysis are provided for devices tested using IEEE 802.11a, IEEE 802.11b, and Bluetooth as well as data from portable laptops/tablet PCs and PDAs (grouping known as PEDs). A comparison was made between wireless LAN devices and portable electronic devices. Spurious radiated emissions were investigated in the radio frequency bands for the following aircraft systems: Instrument Landing System Localizer and Glideslope, Very High Frequency (VHF) Communication, VHF Omnidirectional Range, Traffic Collision Avoidance System, Air Traffic Control Radar Beacon System, Microwave Landing System and Global Positioning System. Since several of the contiguous navigation systems were grouped under one encompassing measurement frequency band, there were five measurement frequency bands where spurious radiated emissions data were collected for the PEDs and WLAN devices. The report also provides a comparison between emissions data and regulatory emission limit						
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